TRANSACTIONS

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AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1179

REMEDIES FOR LANDSLIDES AND SLIPS ON THE KANAWHA AND MICHIGAN RAILWAY.*

By R. P. Black, Assoc. M. Am. Soc. C. E.

With Discussion by Messrs. Charles H. Miller and R. P. Black.

To reach the Kanawha Valley Coal Fields of West Virginia, the southern portion of the Kanawha and Michigan Railway, for 93 miles (from Point Pleasant to Gauley Bridge, W. Va.), is located on the east side of the Great Kanawha River. For about one-third of this distance the road is close to the banks of the river, on a hillside location, where there is practically no valley, the mountains rising directly from the stream.

Owing to the character of the soil, there is considerable trouble due to landslides and slips, the term slips being used where the fill, or embankment under the tracks, settles or slips toward the river.

Excessive rains occur during the winter, and small landslides are numerous, but do little damage; in most cases the water rushing from the mountains brings with it one or two uprooted trees and a few yards of earth. There is much more trouble with the larger landslides, that is, where the whole hillside gradually slips down toward the river, pushing the track ahead of it, and giving bad line and surface. At some places the track is not only pushed out of line but raised.

Landslides occur in almost every case where the hill or mountain side has been cleared of all forest. The top soil, or earth above the

* Presented at the meeting of September 7th, 1910.

rock, which varies in depth from 8 to 20 ft., is mucky clay, which holds water in every low place, apparently being impervious. This clay soil soon becomes saturated, soft, and mucky, and, not having any roots or vegetation to hold it in place, and being on a slope, starts a downward movement, slipping on the rock, covering the ditches and ballast of the track, and pushing it out of line. These so-called landslides do not come down at once, but move slowly, thereby causing no immediate danger. In several places reverse curves have to be given to the alignment, in order to keep the track in surface.

At Point Pleasant, where there was a small landslide, the earth as it came in was removed by a steam shovel at the toe of the slope. The soil at this point was slipping on an inclined stratum of rock, the top of which was smooth and had the appearance of soapstone.

In cases where it was impracticable to remove the slide, the top-soil drainage system on the hillside above was at first tried, but did not work successfully, as the ditches, due to the slippery soil, soon filled up. It appeared that the small amount of surface water collecting in the low places caused by the roughened surface was sufficient to cause the slipping.

At Leon, where considerable expense was incurred in maintaining the track around a slide, the hillside was removed, and the track, for 2 000 ft., was relocated on the rock bottom, obtained by cutting back to a side-hill location. By this method the entire landslide was removed and the track put on rock bed, thereby doing away with the trouble, at a cost of $20 000.

At Cannelton, where the largest slow-moving landslide occurred, the main track had been pushed out of line. Reverse curves were made, in order to get back to the alignment on either side, but, on account of the continual lining out of the track, the curves became too sharp for operation, and the side track between the hillside and the main track became completely covered. As this slide was of such extent and depth (Fig. 1) it was out of the question to remove it in order to get back far enough for a rock sub-grade, as at Leon. The change of line not being feasible, it was proposed to remove part of the landslide, permitting the relocation of the tracks on their original alignment and, after completing this, to protect them from further slides.

A steam shovel was cut in at one end, and removed enough of the landslide to allow the two tracks to be changed to their original loca-

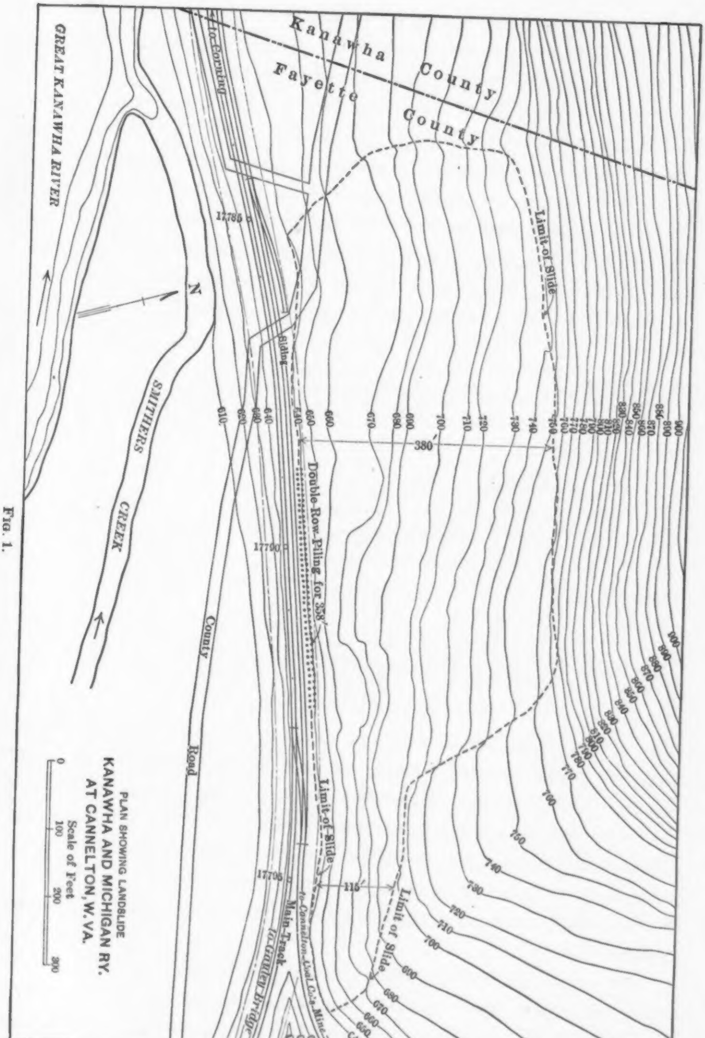
PLAN SHOWING LANDSLIDE
KANAWHA AND MICHIGAN RY.
AT CANNELTON, W. VA.
Scale of Feet
0 100 200 300
Kanawha County
Fayette County
GREAT KANAWHA RIVER
SMITHERS CREEK
N
to Corning
Siding
Double-Row Piling for 338'
Limit of Slide
380'
115'
County Road
Main Track
to Gauley Bridge
to Cannelton Coal Co.'s Mine
17785
17790
17795

FIG. 1.

tion. After the shovel had worked about three days a slide occurred one night, half burying the shovel. Steps were then taken to hold back the hillside before further slides could develop. This was done successfully by driving two parallel rows of piling, 5 ft. apart, about 3 ft. from center to center, as shown on Fig. 2. The upper rows, against the hill, were backed with 3-in. plank, the front rows being driven against this brace in order to aid in supporting the upper row. A 10 by 10-in. stringer was placed against the upper row, and from this 8 by 8-in. braces were carried diagonally, at an angle of 45°, to the lower row of piles, and these were sawed off at the ground level. Steel bands, with 1-in. rods to hold the two sets of piling together, were put on about 8 in. below the top of the brace pile. The depth of penetra-

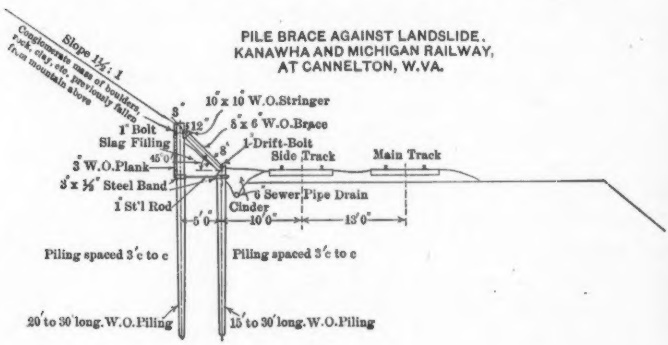

FIG. 2.

tion of the piling varied from 15 to 30 ft. The piling was selected large white oak, and oak timber was used for the stringers and braces. Moving the shovel ahead about 30 ft., then cutting it back, and driving the piling as shown, constituted a day's operation. The work was completed successfully without further serious landslides. In four weeks about 12 000 cu. yd. of earth were removed, the track was thrown back to its original alignment, and the landslide was stopped. This work cost $16 000.

The upper limit of the slide is about 135 ft. above the track. The slide consists of about 200 000 cu. yd. of moving earth. This work was done in the spring of 1907, and has been successful. At several places, due to excessive pressure, the braces have been embedded in

PLATE I.
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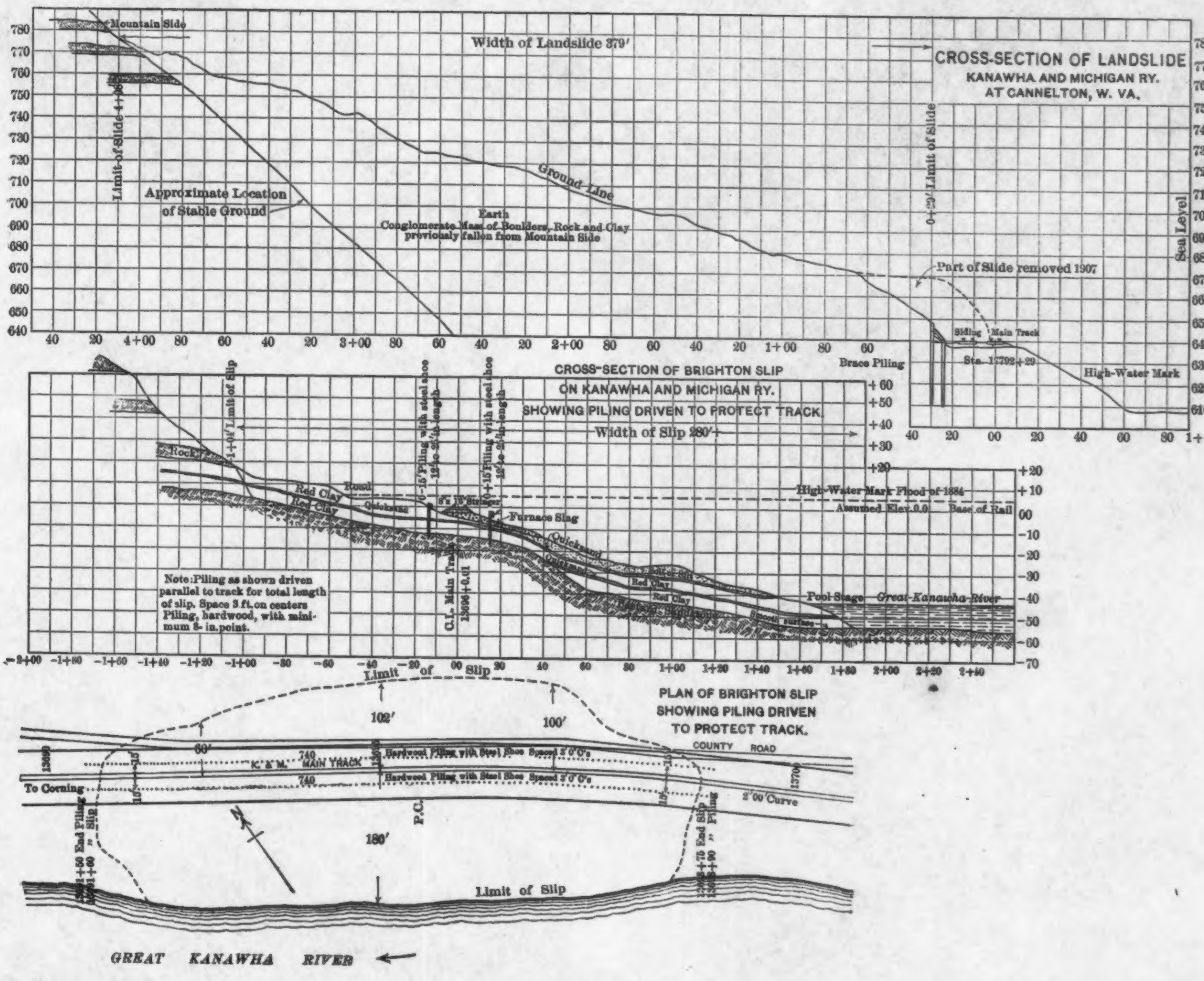
BLACK ON
REMEDIES FOR LANDSLIDES AND SLIPS.



the stringers. The earth from the top of the piling was given a slope of 1½ to 1; at several other points smaller slides have been stopped with one row of piling. The piles were driven 3 ft. apart, center to center, and cut off 3 ft. above the top of the rail, the ground above being given a slope of 1½ to 1. At one or two places, where one row was not sufficient, the trouble was stopped with brace piling. At points where the single row of piling showed signs of leaning, due to the pressure against that part of the piling above ground, this overturning, apparently due to too much length above ground, was stopped by cutting off the piling 3 ft. above the ground and giving the earth above it a slope of 1½ to 1.

In contending with landslides of this character in West Virginia, all that seems to be necessary is to obtain a good toe hold, which stops the movement of the earth above. The so-called slow-moving landslides on the Kanawha and Michigan Railway have been stopped successfully by one of these methods.

Slips.—The term, "slips," as the conventional name indicates, is applied to places where the soil slides into the river. These slips occur when the roadbed is constructed on a fill ranging in depth from 5 to 10 ft., across narrow flats, between the hill and the river. Due to the constant movement of the earth, no trees grow on the land between the river and the railroad. The ground slips gradually into the river where, from time to time, its toe is cut away by the current.

The peculiarity of these slips is the fact that they may continue for one or more seasons without giving any trouble. Slips are due to high water and not to surface water. A quick rise and fall of the river will not cause the soil to move, but continued high water, or several successive floods, will start the slipping action.

In the spring of 1908, the length of track affected by the slips was 7 600 ft., necessitating, at several different points, the maintenance of speeds ranging from 6 to 20 miles per hour for five months, until the dry season, when this slipping action stopped. On Plate I is shown a cross-section of the Brighton slip, which gave the greatest trouble. The section is taken at right angles to the track, the information for which was obtained by levels and test rods driven to rock. A stratum of rock, below the earth, slopes toward the river, ranging from 1:0.2 to 1:1. This rock is covered by successive layers of red clay,

varying from 3 to 6 ft. in thickness. Immediately above the rock, and in thin seams, from 4 to 8 in. thick, between the layers of clay, is found a quicksand mixed with fine clay. When the quicksand and fine clay become thoroughly saturated with water, the mixture affords a smooth surface over which the top soil or successive layers of clay slide toward the river. After high water these seams of quicksand can be traced readily by the water seepage. The quicksand is very slimy, and contains no grit. The water must remain over the ground long enough to force its way back into this quicksand and saturate well before the slipping action can take place.

In 1908, in order to keep the track safe, the gangs on four sections were increased from three—the normal force—to ten men each, and these increased forces were maintained for four months. The tracks had to be resurfaced and lined continually. At three different times, it was necessary to put on filling material and ballast in order to keep the track up to grade. This entailed a cost of $4 400 more than the normal expenses for the year. The track over the slips was not only costly to maintain, but dangerous, due to wrecks resulting from derailments on account of rapid settlement of the roadbed.

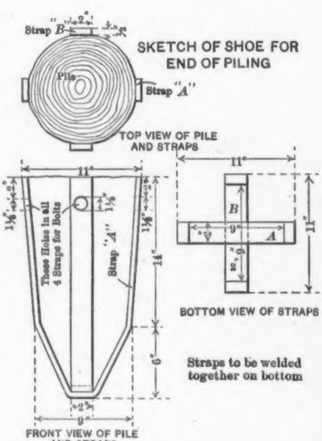


FIG. 3.

At Poca, where a trestle was maintained over a slip for about 800 ft., due to the heavy cost of changing the alignment, the trestlework was filled with heavy quarried rip-rap, and the fill was widened so that the stone reached the river's edge. The weight of this stone fill caused settlement, but, after adding stone from time to time for five years, the roadbed became solid. It is thought that the stone fill settled to the rock stratum below the slip, thereby stopping the movement.

For slips at other points where small fills were maintained, several remedies were suggested, one being to construct, at the river's edge,

a wall which would act as a toe to hold back the moving soil. Owing to the necessary height of the wall, however, this was deemed too costly. At Brighton and Leon slips, where the alignment could not be changed, the remedy shown on Plate I was proposed, the scheme being to drive two rows of piling, one on each side of the track, with a track-driver, the piling to be equipped with steel shoes (Fig. 3) for penetrating the rock strata. It was supposed that, with the toe hold in the rock and the pinning together of the successive moving clay strata, this slipping action in the vicinity of the track would be stopped.

In the spring of 1909, test piling was driven for a distance of 50 ft. in the center of the Brighton slip. Transit observations taken from a base line showed that the piling did not move any appreciable distance. The track held up well within the limits of the piling where, as on either side, it had been necessary to resurface continually.

The test being successful, two rows of piling were driven during December, 1909, on either side of the track at the Brighton slip, and between its limits, for a distance of 740 ft. The piles were equipped with steel shoes and were driven 3 ft. apart, center to center, on the down-hill side. Continuous 8 by 16-in. timber bracing was bolted to the piling. The work was done with a self-propelling track-driver. A temporary spur track was constructed at one end of the slip, thus dispensing with the services of a work train. The cost of this work was as follows:

Hardwood piling, 8 075 ft. at 13 cents	$1 049.75
Steel shoes, 12 690 lb. at 3 cents	380.70
Labor	856.35
Fuel, etc.	120.00
Total	$2 406.80

Up to the present time, this remedy has been successful.

At another point, where the rock strata are not at great depth, it is proposed to go down the hillside about 20 ft. from the track, put down holes about every 20 ft., and blast the smooth surface of the rock. Thus, by roughening the surface and destroying the stratification, the sliding of the clay may be stopped.

DISCUSSION

Mr. Miller.

CHARLES H. MILLER, M. AM. SOC. C. E. (by letter).—The problem of dealing with landslides generally is a most difficult one. It is impossible to give any fixed plan, because, in each particular case, all the local conditions must first be carefully considered.

The remedies described by the author have been in existence much too short a time to determine their permanency, and he fails to state whether or not they are intended to be permanent. It often happens that the life of a temporary structure is of sufficient length to justify its use, and the ones described may have been constructed for this reason.

In carrying out these remedies, as far as can be learned, very little, if any, effort was made to get at and remove the source of the trouble.

At Cannelton, W. Va., sole reliance seems to have been placed on a double row of braced piling to hold back a mass of moving material extending up the slope about 380 ft. and having a depth averaging at least 30 ft. A part of this mass was removed near the toe, or just above the piling. The writer can readily understand how the sliding at this point may be checked by making the new slope flatter than the old one, but is in doubt as to whether the flattening was extended far enough up the slope to prevent the wet material above from again sliding down over the new slope and finally over the top of the pile retaining wall.

At the Brighton slip, the assumption seems to have been made that, by driving the piles into a rock bottom, they would get a toe hold sufficient to prevent further sliding of the mass above. First, what assurance is there that the iron straps, placed on the points of the piles for the purpose of causing them to penetrate the rock, do not defeat this very purpose, by cutting into the points and aiding the battering of the same? Assuming that the points get a good toe hold, what is to prevent them from bending over as the mass moves down the slope from above? Is it not possible that success, if obtained in this case, is due to the fact that sub-drainage occurs down each of the piles, which are only 3 ft. apart, thus conducting the water to a stratum through which it passes to the river without causing movement, thus permitting the mass below the upper row of piles to dry out and become stable?

To correct the trouble at this point, it would seem well, first, to protect the toe of the slope with mattress or rip-rap so as to be certain that the river could not continue scouring off the support to the mass above; next, to excavate a trench along the upper side of the track, making it of such depth as to get below the movement at all points, and place therein a tile drain, the entire trench to be then filled with cinders; and, finally, to place surface drains well above the limits of the movement.

The Cannelton situation is a much more difficult one to meet, but good surface drains should be placed around the top of the movement, in stable material, where they will not require much maintenance if constructed with proper slopes. Drainage ditches should be placed around over the slide and given much close attention. It is not economical to attempt general ditches, but the water-pockets and low places should be drained quite often, especially after each hard rain. The chief difficulty to-day is in getting the section foreman to realize how much work he can relieve himself of in the end by frequent and careful attention to drainage. Mr. Miller.

The claim that roots or vegetation will hold in place mucky clay from 8 to 20 ft. deep, on a slope—or will have any appreciable effect whatever in that direction—is not a good one.

Blasting up the surface of the rock on which there is sliding earth does not stop the sliding because of the roughened surface, but because a passageway is made for the water, enabling it to get away from the clayey material above, thus allowing it to dry out.

It often proves economical in the end to abandon the old line and relocate where a solid foundation can be secured. In all extensive slides it is well to take a sufficient number of accurate borings before planning a remedy.

R. P. Black, Assoc. M. Am. Soc. C. E. (by letter).—There have been many landslides, or so-called slips, on the Kanawha and Michigan Railway. Owing to the geological formation, the conditions between Raymond City and Point Pleasant, on the Ohio River at the mouth of the Kanawha River, differ greatly from those above Charleston, as at Cannelton. Many of the remedies tried are known to be permanent, as at Leon, where the hillside was cut away in order to obtain a solid roadbed, virtually rock; and at Poca, where rock filling was deposited on the fill until the soft clay, because of the weight above it, slipped out and was replaced by the rock. Mr. Black.

The railroad company could not afford the large sums of money which would have been necessary in order to make changes in the line at the points mentioned, and therefore it was economical to resort to the remedies described, with the hope that they might be permanent. This is thought to be true at those slips where the piling penetrated the soapstone strata and was far enough below the ground line to prevent decay. In the case of the landslide at Cannelton, the exposed piling will probably have to be renewed, but it was thought that in about 8 years it might become necessary to double track at this point, thereby causing changes in the alignment, or that the greater part of the landslide might be removed and used for filling. At some points, where piling was driven 15 years ago, permanent results have been obtained.

To one not familiar with the geology of the country, the Brighton

Mr. Black. slip appears to start at the top, and the assumed angle of repose seems to be less than that of the wet material in its sliding state. This is not the case, however, for the sliding or slipping starts first at the bottom on the greasy soapstone, which, when uncovered, presents a smooth surface, resembling the tops of large mushrooms, and is so slippery when wet that it is difficult to stand on it. The water which comes from the underground strata of the hill or mountain, or is forced in by high waters in the river, follows this soapstone surface back to the river. The trouble, therefore, is underground and not on the surface, for, by stopping the slipping action just above the soapstone, the superimposed earth remains stable. This also indicates that it should be possible to stop the sliding by roughening the surface of the soapstone by blasting. Surface ditches have been maintained at some of the landslides, thereby relieving the situation, but it has been impossible to maintain such ditches at other places on account of the recurring cracks in the ground and the unstable condition of the soil.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1180

THE RECONSTRUCTION OF THE PASSENGER TERMINALS AT WASHINGTON, D. C.*

By W. F. Strouse, M. Am. Soc. C. E.

Introduction.

Early Legislation.—The question of abolishing grade crossings in the District of Columbia was under discussion for many years, and numerous plans were prepared with this object in view. As early as 1896 it fell to the writer's lot to be assigned the duty of making studies for the reconstruction of the Baltimore and Ohio Railroad Company's yards, buildings, and lines within the District of Columbia. At that time, of 28 streets and avenues crossed by the Baltimore and Ohio Railroad Company's Washington and Metropolitan Branches in the city and suburbs, only one was carried over or under the railroad by a suitable bridge.

None of the many plans and propositions submitted seemed to meet the views of the District and National Authorities until 1900, when a plan presented by the Baltimore and Ohio Railroad Company seemed to be nearer to meeting the requirements than any previous scheme. At about the same time, the Baltimore and Potomac, now the Philadelphia, Baltimore, and Washington Railroad Company, submitted plans for the reconstruction of its lines and terminals in the southern section of the city, which likewise met with the approval of the District and National Authorities.

* Presented at the meeting of October 19th, 1910.

On February 12th, 1901, Congress passed two separate Acts relating to the reconstruction of railroad lines and terminals, and the elimination of grade crossings in the City of Washington. One of these Acts authorized the Baltimore and Ohio Railroad Company to construct a passenger and freight terminal at Delaware Avenue and C Street, N. E., with an elevated approach of masonry arches and retaining walls. The other Act authorized the Philadelphia, Baltimore, and Washington Railroad Company to enlarge its present Sixth Street Station, to elevate and depress its line on Maryland and Virginia Avenues, and to improve its alignment on Virginia Avenue and through Garfield Park.

Historical.—About two months prior, exercises commemorative of the one hundredth anniversary of the removal of the seat of the government to the District of Columbia were held at the White House and Capitol. These exercises were participated in by the Governors of the States as well as by the officials of the General Government and representatives of foreign powers. The key-note of this celebration was the improvement of the District of Columbia in a manner commensurate with the dignity and resources of the American Nation.

During the same period the American Institute of Architects held its session in Washington, and, as a result of a series of papers read and discussed at that time, the Institute appointed a committee on legislation. Consultations between that committee and the Senate Committee resulted in the Senate ordering the preparation and submission of a general plan for the development of the entire park system of the District.

The Senate Committee was authorized to sit during the recess of Congress and to secure the services of such experts as might be necessary to obtain a proper consideration of the subject. The desirability of a comprehensive plan for the development of the District of Columbia, and particularly the City of Washington, had long been felt by all. This had been especially true during recent years when questions relating to the location of public buildings had to be considered, the absence of an approved plan either causing the postponement of decisions or resulting in compromises that marred the beauty and dignity of the National Capital.

On March 19th, 1901, thirty-five days after the passage of the above mentioned Acts, the sub-committee of the Senate Committee met the representatives of the American Institute of Architects and agreed to

the proposition of the latter that Mr. Daniel H. Burnham, of Chicago, Ill., and Mr. Frederick Law Olmsted, of Brookline, Mass., be engaged as experts, with authority to add to their number. The task was accepted by these gentlemen, who invited Mr. Charles F. McKim and Mr. Augustus St. Gaudens, of New York City, to act with them in the preparation of plans.

As Director of Works of the World's Columbian Exposition, held in Chicago in 1893, Mr. Burnham was instrumental in securing the adoption of a scheme of construction which placed that exposition in the very front rank of international expositions, and, by the display of rare executive ability, brought about and maintained that effective co-operation of architects and artists which gave to American art a new direction and a tremendous impetus.

Mr. Olmsted's name is synonymous with what is best in modern landscape architecture. He is the consulting landscape architect, not only of the vast system of parks and boulevards of Boston and suburbs, but of many other cities. To his inherited tastes is added the highest training, both practical and theoretical.

As architect of the Boston Public Library, the Rhode Island Capitol, the fence and new buildings of Harvard, and other structures of monumental character, Mr. McKim, now deceased, was recognized as without a superior among American architects, on account of the simplicity, directness, and scholarly qualities of his work.

In Mr. St. Gaudens, whose recent death removed a man who unquestionably stood first among American sculptors, the commission included one whose criticisms had the authority of law among architects and artists.

Immediately following the appointment of this commission, a detailed examination of the topographical features of the District of Columbia was made, and preliminary plans were prepared. The commission was forced to the conclusion that a proper treatment of the park system could not be had without the exclusion of the Philadelphia, Baltimore, and Washington Railroad Station from public grounds, and the Baltimore and Ohio Railroad from a site one square distant from the Capitol grounds.

The right of occupation of the Mall by the Philadelphia, Baltimore, and Washington Railroad dates back to March 23d, 1871, at which time the local government of the District of Columbia granted to the

Baltimore and Potomac Railroad Company the necessary land. This action was confirmed by Congress on May 21st, 1872. At the time this grant was made the development of this section of the city was such that the conditions were improved by the change. Inasmuch, however, as the grant was confirmed by Congress, the Railroad Company held the right to use the property by title good both in law and equity. In addition to this right Congress had just passed an Act permitting it to enlarge its present facilities, in consideration of the surrender of certain street trackage and the elevation of its tracks within the City of Washington.

Some time prior to the appointment of the above mentioned committee, Mr. Burnham, chairman of the commission, had prepared preliminary plans for the reconstruction of the Philadelphia, Baltimore, and Washington Railroad Station, as above provided. After consultation with the District sub-committee, he recommended that the Philadelphia, Baltimore, and Washington Railroad Company build its station on the south side of the Mall so as to remove its tracks and buildings from public grounds. The architectural advantages of the proposed site were set forth with such vigor as to command serious consideration. This resulted in delaying the work on the terminals covered by the two Acts.

The commission, in order to make a closer study of the practice of landscape architecture as applied to parks and public buildings, made a trip to Europe, visiting Rome, Venice, Vienna, Paris, Budapest, and London, and their suburbs. While on this trip the commission met the President of the Pennsylvania Railroad Company, who agreed to consider the question, not of moving the station to the south side of the Mall, but of withdrawing entirely from that region and uniting with the Baltimore and Ohio Railroad Company in the construction of a union station on the site established by previous legislation for that road, provided that suitable legislation could be obtained to compensate his company for the expense such a change would involve, and provided, also, that the approaches to the new station be made worthy of the building the railroad companies proposed to erect.

Selection of Site.—To select a site and prepare a plan which would provide the facilities required for conducting the business of all railroad companies entering Washington involved considerable thought

PLATE II.
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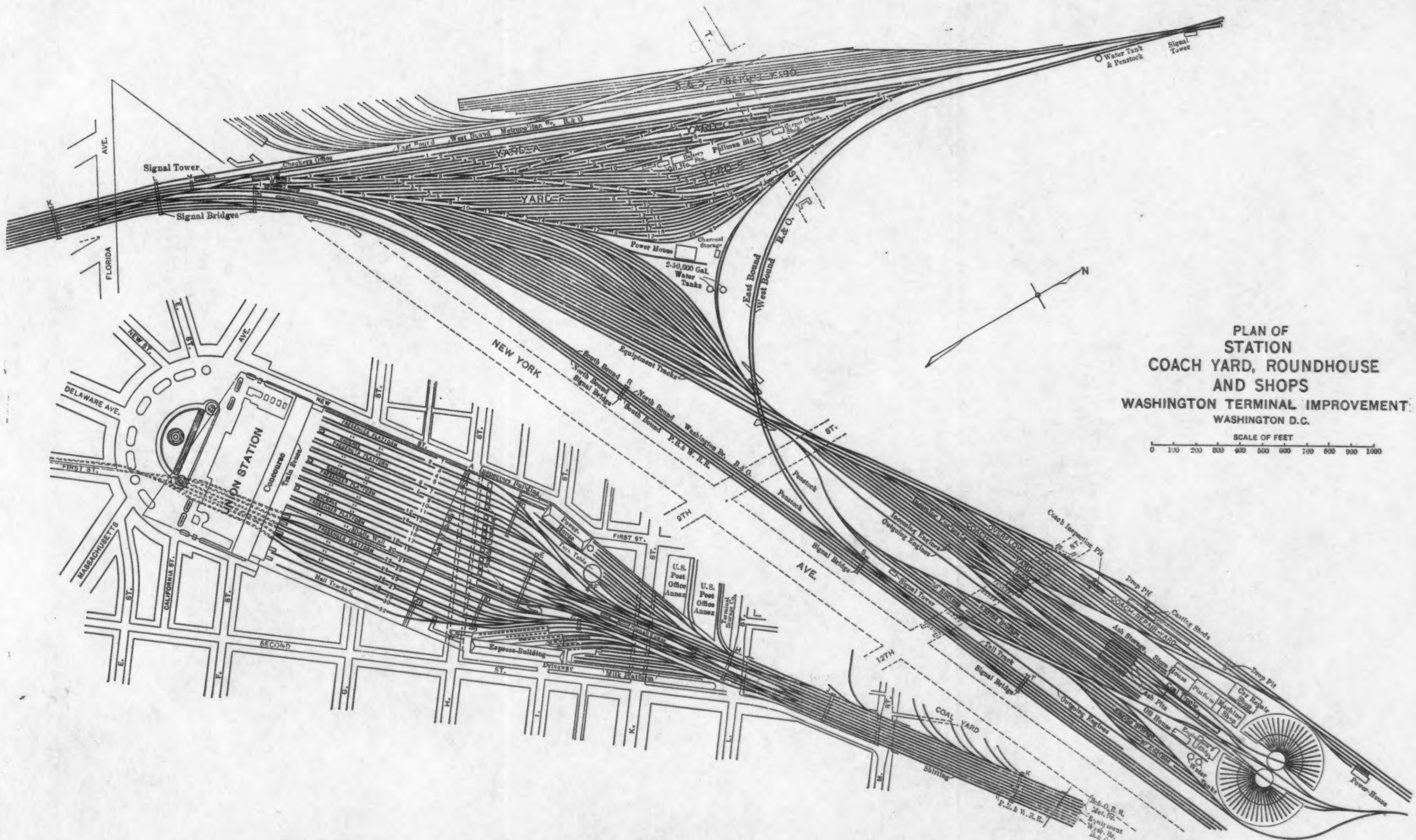
STROUSE ON
THE WASHINGTON TERMINAL STATION.



and labor on the part of the officers of the railroad companies and the architects. The site selected by the Baltimore and Ohio Railroad for a passenger terminal at Delaware Avenue and C Street received due consideration, and contained many desirable features. It was felt, however, that the erection of a train-shed extending across Massachusetts Avenue, one of the main thoroughfares of the city, would destroy the vista, and the construction of a large station at this point would place a busy commercial center too near the Capitol grounds.

Other locations for the station were suggested, especially a site on the north side of Staunton Square. This location simplified the northern approach, but required a longer and more expensive approach from the south. In the consideration of the various sites, the commission kept in mind the development of the park system. This seemed to require the complete removal of railroad facilities from the Mall and the abandonment of the Baltimore and Ohio site at C Street. After due consideration the commission suggested the intersection of Massachusetts and Delaware Avenues as a proper site. This placed the station on the line of the proposed Baltimore and Ohio development, but about three blocks farther from the Capitol grounds.

This location was accepted by the railroad companies as the site for a union station which would permit of a treatment in harmony with the general park system, and at the same time allow a proper development of the Mall. Owing to the relative location of the two railroad systems and the distance separating them, it was difficult to secure a proper connecting link between them without awakening unfavorable sentiment. With this location, however, there seemed to be only one possible connection between the existing lines in the northern and southern sections of the city and the union station, namely, by way of First Street, E., between the Library of Congress and the Capitol and Delaware Avenue, a suggestion made some years ago but against which there was considerable feeling, both as to the construction and the operation of a tunnel between two prominent public buildings.

Additional Legislation.—Plans were then prepared and a bill was introduced into Congress, at the session of 1902-03, providing for the construction of a union station of monumental design on the north side of Massachusetts Avenue, with the necessary north and south

approaches. This bill, supplementary to some extent to the Acts of 1901, but covering such changes as were necessary to meet the requirements of the companies concerned, was passed on February 28th, 1903.

In general, it adopted for the north approach the plans of the Baltimore and Ohio Railroad under its Act of 1901. It provided for the abandonment of the Sixth Street Station and the removal of the tracks of the Philadelphia, Baltimore, and Washington Railroad from the Mall; the construction of the Baltimore and Ohio Railroad freight terminal at New York and Florida Avenues, N. E., about one mile north of its original location; its coal yard on Square 711 adjoining Delaware Avenue between M and N Streets, and the necessary shops and yards east of Eckington. It also provided for the construction of a new connection with the Philadelphia, Baltimore, and Washington Railroad at Magruder, known as the Magruder Branch.

The problem of bringing together by legislation two large competing railroad lines into a union station, particularly in a section of Washington so far developed and surrounded by so much sentiment, was not easily accomplished. The people had cherished the hope for many years that a union station might be constructed, but the suggestion received no encouragement from the railroad companies.

In line with the proposed treatment of the park system, the front of the station building was located 150 ft. north of the intersection of Massachusetts and Delaware Avenues. To make the structure more imposing, the main floor elevation was fixed at 58 ft. above mean tide, or about 35 ft. above the original ground level. On masonry foundations, carried to this elevation, has been placed a building, the highest point of which is 122 ft. 10 in. above the floor level.

The ground occupied by the west end of the building was formerly used by the Baltimore and Ohio Railroad as a coal yard; the east end is on ground originally occupied by private residences; and the center occupies Delaware Avenue, formerly the roadbed of the Baltimore and Ohio Railroad.

North Approach.—As previously stated, the north approach for both companies occupies the route selected by the Baltimore and Ohio Railroad and covered by its Act of 1901, except that there has been a marked increase in the number of tracks. The roundhouses and shops, which by former legislation were to be located in Eckington,

FIG. 1.—WASHINGTON TERMINAL STATION: FRONT ELEVATION.

FIG. 2.—WASHINGTON TERMINAL STATION: INTERIOR OF MAIN WAITING-ROOM DURING CONSTRUCTION.

have been erected, about ¾ mile farther east, on what was formerly known as the Ivy City race-track property. At this point facilities have been provided for caring for the rolling stock of all companies operating trains into the union station.

Roughly speaking, the north approach occupies Delaware Avenue from Massachusetts Avenue to Florida Avenue. At this point the tracks of the Washington Branch of the Baltimore and Ohio Railroad and the Philadelphia, Baltimore, and Washington Railroad curve to the east to a line parallel to New York Avenue and 100 ft. northwestward therefrom. At Montana Avenue these lines diverge, the Washington Branch connecting with the old line at Langdon, and the Philadelphia, Baltimore, and Washington continuing eastward and joining the old line at Magruder. From Florida Avenue the Metropolitan Branch of the Baltimore and Ohio Railroad continues northward to a connection with the old line near University Station.

In making these changes the old lines of both the Washington and Metropolitan Branches of the Baltimore and Ohio Railroad were abandoned for a distance of about 3 miles each. The roadbed of the Metropolitan Branch for about half the distance, however, is used in the freight yard development. The Philadelphia, Baltimore, and Washington Railroad Company retains all its old lines except from Maryland Avenue to the old Sixth Street Station, and there were some slight changes in the yard development.

South Approach.—The south approach is by way of a double-track tunnel under First Street, E., from the station at Massachusetts Avenue to B Street, S. E., from which point the line curves to the west through private property to New Jersey Avenue and D Street, S. E. From this point to a connection with the Philadelphia, Baltimore, and Washington Railroad tracks on Virginia Avenue near Second Street, S. W., the line is by open cut and viaduct.

From Second Street and Virginia Avenue west to a point near Seventh Street an elevated structure wide enough for four tracks was built in the bed of Virginia Avenue. At Seventh Street the line curves into Maryland Avenue which has been converted into an open cut wide enough for four tracks. At Fourteenth Street the line curves to the south to a connection with the new steel bridge across the Potomac River immediately west of the site of the old Long Bridge. The double-track connection to the south is used only as a passenger

line, the handling of freight being prohibited by the Act of Congress except in case of accident, and then only for a limited time.

East of Virginia Avenue and Second Street, W., all tracks of the Philadelphia, Baltimore, and Washington Railroad are used exclusively for handling freight. All passenger traffic is now handled over the Magruder Branch, the north approach to the station, and through the tunnel to the south.

STATION.

In the design of the station much thought was given to the architectural features. Since Greece and Rome have furnished architectural inspiration for so many of the public buildings of Washington, a freely interpreted classic may be considered as the recognized architecture of these structures, and, as the new station was to be the one gateway of the Capital, it seemed fitting that the architectural motives should be drawn from the triumphal arches of Rome.

Some of the elements entering into the design of the terminal were unique. In most cities the probable future growth and nature of the traffic plays an important part in the planning of a passenger terminal. Washington has very little suburban traffic, and, as it will never become a commercial center, the question of providing for future growth was of minor importance. The main problem was how to care for and provide against abnormal conditions, which arise at least once every four years. The handling of inauguration crowds has always been a heavy expense to the railroads because they have had to provide such elaborate temporary facilities. On the other hand, to provide adequate permanent facilities meant a large expenditure, with the attendant heavy carrying charges. On account of the dilapidated condition of the passenger facilities owned by both companies, and the urgent need of larger and better terminals, a union terminal seemed to show advantages over the separate stations provided for in the Acts of 1901.

The layout embraces every feature and facility involved in the construction of a first-class railroad, including a depot building planned and constructed after the most modern lines, and containing every feature for the convenience, comfort, and pleasure of the traveling public; the most complete and up-to-date facilities for conducting the business of a large railroad station; a main power-plant for furnishing power of every kind required for the successful operation of the station and yards; a large and completely equipped express terminal for car-

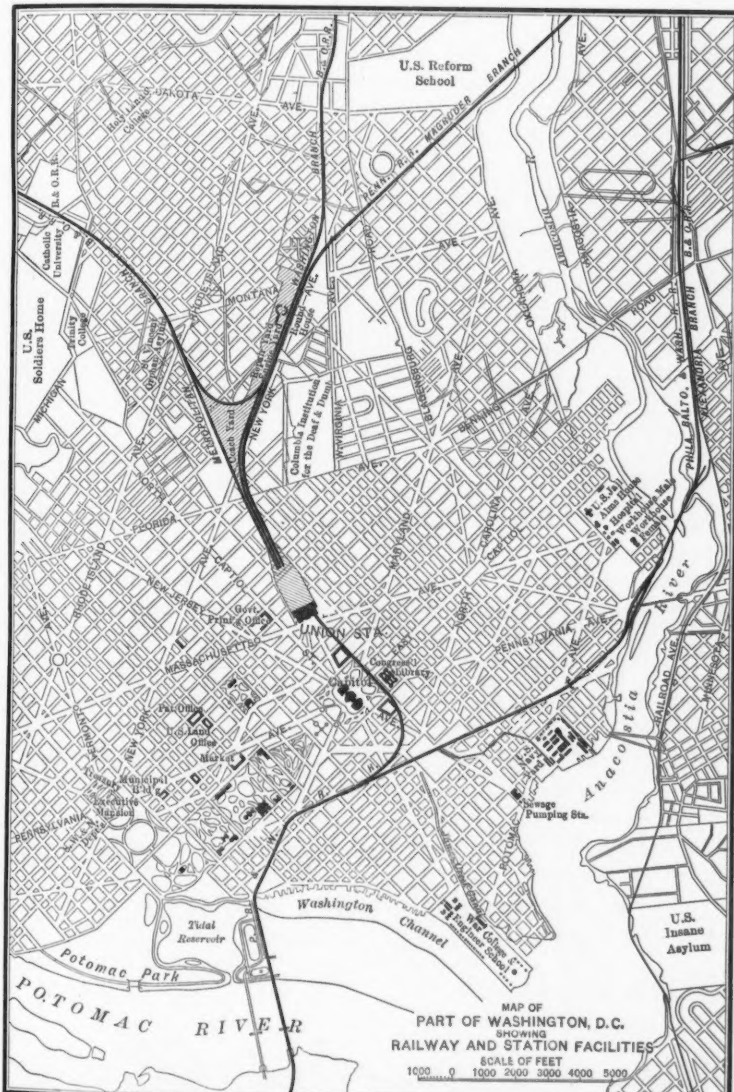

MAP OF
PART OF WASHINGTON, D.C.
SHOWING
RAILWAY AND STATION FACILITIES
SCALE OF FEET
1000 0 1000 2000 3000 4000 5000
UNION STA.
Capitol
U.S. Reform School
U.S. Soldiers Home
Catholic University
Trinity College
Tidal Reservoir
Potomac Park
POTOMAC RIVER
Washington Channel
Anacostia River
U.S. Insane Asylum
Sewage Pumping Sta.
Congress'l Library
Govt. Printing Office
Pat. Office
U.S. Land Office
Market
Municipal Bld'g
Executive Mansion
Columbia Institution for the Deaf & Dumb
Coach Yard
Round House

FIG. 1.

ing for the express business handled by the Adams, Southern, and United States Express Companies; a modern commodious roundhouse and shop layout for caring for repairs to equipment; the most complete interlocking layout and intercommunication system ever constructed; one of the most complete passenger equipment yards ever built, and a track system covering yards and main tracks within the passenger terminal zone aggregating about 60 miles of single track.

The head-house is 626 ft. 10 in. long and 210 ft. 9 in. wide, exclusive of the space taken up by the columns in front of the central pavilion or main portico. The front and ends are made up of groups of semicircular arches characteristic of Roman architecture. The main portico or central pavilion consists of three arches, each 29 ft. 6 in. wide and 48 ft. 9 in. high. Flanking it on either side are seven arches, each 12 ft. 4 in. wide and 24 ft. 8 in. high, while the end pavilions are composed of arches 22 ft. wide and 38 ft. 6 in. high.

The west end is made up of five arches 19 ft. 2 in. wide and 37 ft. 7 in. high, and one arch 12 ft. 4 in. wide and 24 ft. 8 in. high. The former are used as exits for carriages from the carriage porch, the latter to carry out the open portico treatment across the front. At the east end there are five arches, 12 ft. 6 in. wide and 24 ft. 8 in. high, leading to the open portico, two windows with arch treatment, and one arch, 22 ft. wide and 38 ft. 6 in. high, leading to a carriage pavilion.

The east pavilion leads to a suite of rooms for the use of the President and the guests of the Nation, the west pavilion to the carriage porch at the west end of the ticket lobby. The central and end pavilions are connected by a portico or loggia from 14 ft. 6 in. to 16 ft. 6 in. wide, the portico and pavilions forming a continuous covered porch the entire length of the structure, and affording protection from the elements. The east and west wings of the building are 69 ft. 7½ in. above the floor level, and the domes over the carriage entrances are 78 ft. 3½ in. above the same point. The dome over the main waiting-room is 122 ft. 10 in. high.

The concourse in the rear of the head-house is 760 ft. long and 130 ft. wide, exceeding by nearly 9 ft. the length of the Capitol. It is covered by a segmental arched ceiling 45 ft. high in the center and 22 ft. at the springing line above the main floor. About 40% of the ceiling area is of glass, the remainder is artistically coffered ornamental plaster. The concourse is divided by the usual train fence into two

FIG. 1.—WASHINGTON TERMINAL STATION: CONCOURSE.

FIG. 2.—WASHINGTON TERMINAL STATION: GENERAL WAITING-ROOM.

sections, that on the station side being 83 ft. wide, and that on the track side, 47 ft.

The general waiting-room has a clear width of 120 ft., is 219 ft. long, exclusive of the colonnades, and is covered by a Roman barrel-vaulted ceiling, its highest point, exclusive of coffers, being 96 ft. above the floor level. The decorations are sunken panels patterned after the baths of Diocletian. It is lighted by a semicircular window 72½ ft. in diameter at the east end, by three semicircular windows in the south side and five on the north side, each 27½ ft. in diameter, and by the glass roof over the ticket lobby at the west end. Imperial Rome at her greatest did not possess a hall of such proportions.

The fronts of the large piers along the north side of the room are occupied by two granite drinking fountains and two telegraph booths, one for the Western Union and the other for the Postal Telegraph Company. There are similar drinking fountains in front of the corresponding piers in the south side, and the spaces in front of the two remaining piers are occupied by a news-stand and a flower-booth. In the south side of this room there are two semicircular alcoves. The one near the west end of the room contains a public telephone station with an exchange and fourteen booths. The alcove near the east end contains a drug store with the usual counters, cases, and a soda fountain. For the comfort of patrons, the central portion of the waiting-room is fitted with large comfortable settees, arranged to provide ample space for circulation between them at all times.

The dining-room at the east end of this hall is 80 ft. wide and 100 ft. long, and the ceiling is 29 ft. 6 in. high. On the north and south sides there are alcoves which add greatly to the coziness of the room. On account of its location, no light could be obtained from the sides except through clerestory windows. To overcome this difficulty, a saw-tooth roof was provided, the north inclines of which are of glass. The ceiling is artistically paneled, and nearly the entire area is covered with glass.

The lunchroom is 32 ft. 6 in. wide, 120 ft. long and has a ceiling 28 ft. 8 in. high. It is on the north side of the dining-room, overlooking the concourse. The large windows in the north wall and the clerestory windows furnish ample natural light. Like the dining-room, the lunchroom has alcoves on the north side.

The women's waiting-room is 42 ft. wide and 75 ft. long, with a ceil-

ing 29 ft. 2 in. high. It is south of the dining-room, and is a large cheerful apartment with windows opening on the portico and overlooking the plaza.

The smoking-room is 37 ft. wide and 54 ft. long, with a ceiling 28 ft. 6 in. high, and is at the west end of the general waiting-room, fronting on the portico. Adjacent to the smoking-room is found the barber shop and shoe-shining establishment.

The ticket lobby, 50 ft. wide and 100 ft. long, covered by a semicircular glass roof, is at the west end of the general waiting-room, immediately north of the smoking-room, the ceiling being about 60 ft. above the floor.

The baggage checking-room is on the north side of the ticket lobby; it is 49 ft. wide and about 124 ft. long, with a ceiling 20 ft. high. On the south side are the ticket-offices, consisting of a Pullman ticket-office and seven railroad ticket-offices, at each of which tickets over all railroads entering Washington can be purchased.

The bureau of information and the stop-over ticket-offices are under the colonnade at the entrance to the ticket lobby, and there is a parcel-room at the northwest corner of the main waiting-room, having windows opening into the main waiting-room and on the concourse.

The state apartment, at the extreme east end of the station, consists of a reception-room 30 ft. wide and 70 ft. long with a ceiling 28 ft. 8 in. above the floor, and with north and south vestibules and private retiring-rooms on either side of the main entrance.

There are large and commodious toilet-rooms adjoining the women's waiting-room at the east end of the station, and adjoining the barber shop at the west end. In both cases there are a number of pay toilets, fitted out in the best manner with lavatories, where patrons, by paying a small fee, may obtain a towel, soap, comb and brush, and hot and cold water.

Statuary and Inscriptions.—The cómplete architectural treatment of the front elevation of the station includes six stone statues and four eagles, the former over the central pavilion, the latter over the carriage entrances at the east and west ends. This statuary is placed in front of the great friezes over the main entrance arches and over the carriage archways, and, with the inscriptions in the panels between, have been made a special architectural feature.

Before the adoption of the scheme now being executed, a number of suggestions for the subjects of the statues and inscriptions were

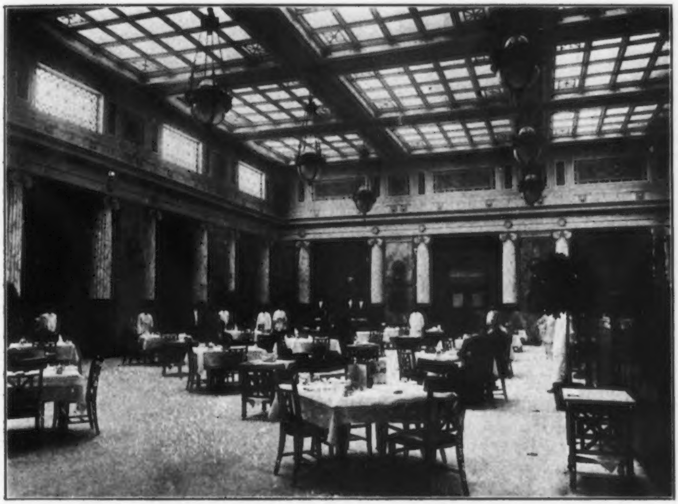


FIG. 1.—WASHINGTON TERMINAL STATION: DINING-ROOM.

FIG. 2.—WASHINGTON TERMINAL STATION: BALCONY IN MAIN WAITING-ROOM, SHOWING LIGHTING EQUIPMENT.

secured, ranging from the explorers and discoverers of this country to the various inventors who have had most to do with the development of transportation. The general architectural treatment of the building, however, was such as to preclude the usual portrait statues. To make them take their place as part of the architecture required that they be limited to allegorical draped figures, forming simple massive silhouettes against the vast frieze.

In the development of the complete scheme, embracing the subjects for the statuary, with appropriate inscriptions in the intervening panels, Ex-President Charles W. Eliot, of Harvard University, was consulted. The result is an appropriate and adequate treatment of the decorative frieze over the doorway of the vestibule to the Capital of the Nation.

The general decorative features of the main entrance to the building consist of six massive stone columns, two on each side and one in front of each pier supporting the main arches. Upon pedestals on the tops of these columns the granite statues, about 18 ft. high, will be placed, those on the west side of the entrance representing Prometheus and Thales, typifying Fire and Electricity, those on the east side Ceres and Archimedes, typifying Agriculture and Mechanics, while Freedom and Imagination are depicted by the central figures. Those on the west side represent two of the great forces connected with the operation of railroads, those on the east owe much of their development and wealth to the railroads. The central figures typify the atmosphere of freedom in which the inventive imagination has been able to accomplish such great results.

The columns flanking the carriage entrances are surmounted by stone eagles about 8 ft. high. The following inscriptions have been cut in the three granite panels over the main entrance:

WEST (PROMETHEUS AND THALES).

FIRE—GREATEST OF DISCOVERIES
ENABLING MAN TO LIVE IN VARIOUS CLIMATES
USE MANY FOODS—AND COMPEL
THE FORCES OF NATURE TO DO HIS WORK

ELECTRICITY—CARRIER OF LIGHT AND POWER
DEVOURER OF TIME AND SPACE—BEARER
OF HUMAN SPEECH OVER LAND AND SEA
GREAT SERVANT OF MAN—ITSELF UNKNOWN

THOU HAST PUT ALL THINGS UNDER HIS FEET

CENTRAL (FREEDOM AND IMAGINATION).

SWEETENER OF HUT AND OF HOME
BRINGER OF LIFE OUT OF NOUGHT
FREEDOM O FAIREST OF ALL
THE DAUGHTERS OF TIME AND THOUGHT

MAN'S IMAGINATION HAS CONCEIVED ALL
NUMBERS AND LETTERS—ALL TOOLS VESSELS
AND SHELTERS—EVERY ART AND TRADE—ALL
PHILOSOPHY AND POETRY AND ALL POLITIES

THE TRUTH SHALL MAKE YOU FREE

EAST (CERES AND ARCHIMEDES).

THE FARM—BEST HOME OF THE FAMILY—MAIN
SOURCE OF NATIONAL WEALTH—FOUNDATION OF
CIVILIZED SOCIETY—THE NATURAL PROVIDENCE

THE OLD MECHANIC ARTS—CONTROLLING NEW
FORCES—BUILD NEW HIGHWAYS FOR GOODS
AND MEN—OVERRIDE THE OCEAN—AND MAKE
THE VERY ETHER CARRY HUMAN THOUGHT

THE DESERT SHALL REJOICE AND BLOSSOM
AS THE ROSE

In the panels over the entrances to the carriage porch and state apartment the following inscriptions have been cut:

CARRIAGE PORCH (SOUTH ELEVATION).

HE THAT WOULD BRING HOME THE
WEALTH OF THE INDIES MUST CARRY
THE WEALTH OF THE INDIES WITH HIM
SO IT IS IN TRAVELLING—A MAN
MUST CARRY KNOWLEDGE WITH HIM
IF HE WOULD BRING HOME KNOWLEDGE

STATE APARTMENT (SOUTH ELEVATION).

LET ALL THE ENDS THOU AIMST AT BE
THY COUNTRY'S—THY GOD'S AND TRUTH'S

BE NOBLE—AND THE NOBLENESS THAT
LIES IN OTHER MEN—SLEEPING BUT
NEVER DEAD—WILL RISE IN MAJESTY
TO MEET THINE OWN

STATE APARTMENT (EAST ELEVATION).

WELCOME THE COMING
SPEED THE PARTING GUEST

VIRTUE ALONE IS SWEET SOCIETY
IT KEEPS THE KEY TO ALL
HEROIC HEARTS AND OPENS YOU
A WELCOME IN THEM ALL

The scope of the idea seems to harmonize with the magnificent scale and the monumental character of the building, as well as with the great rôle it is to play in the life of the Capital.

Plaza.—To provide a proper setting for the station, a plaza 940 ft. long and 540 ft. wide, with appropriate decorations, was constructed in front of it. As previously stated, the average ground level in this vicinity was such as to require a fill of about 35 ft. around the station and over a large portion of the space occupied by the plaza. This naturally involved radical changes in the elevations of the streets contiguous to the station and plaza. With the exception of the new streets along the east and west ends of the station, however, the grades of new and existing streets were changed so as to provide easy approaches to the station.

As the original ground had a slight fall toward the southwest, with a corresponding rise toward the east, the changes toward the latter direction were naturally much shorter than those toward the west. In addition to the existing streets, four new ones were created, and several of the existing ones were changed so as to conform better to the general plaza scheme.

The decorations immediately in front of and along the sides of the east and west carriage entrances to the station consist of handsome stone balustrades, upon which at proper intervals there are ornamental iron lamp-posts. Flanking the approaches to the carriage porch and state apartment from the south, the end posts of the balustrades support ornamental iron rostral columns about 30 ft. in height above the pavement level. The tops of these columns terminate in spheres surmounted by eagles.

Each rostral column contains two inverted, series, arc lamps enclosed in 20-in. globes, about 16 ft. above the street level. All other lamp-posts on these balustrades are about 16 ft. above the street level,

each containing one inverted, series, arc lamp enclosed in a globe 26 in. in diameter.

Two other groups of balustrades surround handsome stone fountains opposite the centers of the east and west wings of the station. There is a line of ornamental iron lamp-posts, 16 ft. high, supported on granite pedestals, between the ends of the balustrades around the fountains, effecting a uniform treatment across the entire front of the station. There are also lines of ornamental iron lamp-posts, 11 ft. high, arranged for use with incandescent lamps, around the outer edges of the central island and plaza, and there is a line of arc lamp-posts, 29 ft. 3 in. above the plaza grade, on islands on a circle inside the street-car tracks. Two series arc lamps are suspended from a cross-arm near the top of each of these lamp-posts, the centers of the lamps being 24 ft. above the street level.

All stone used in the decoration of the plaza, except that in the bowls of the fountains, is white granite, from Bethel, Vt., from the same quarry as that used in the station building. The fountain bowls are of green granite, from Rockport, Me. The upper bowls are 13 ft. in diameter, and cut from a single piece of stone; the lower bowls are 22 ft. 6 in. in diameter, the rims being made from eight separate pieces of granite. The bottoms of these bowls are of reinforced concrete, and are lined with sheet lead.

Immediately in front of the central pavilion, there are foundations for three ornamental iron flagstaffs, 110 ft. in height, the ornamental base and decorative portions of which are to be executed in bronze. For still further decoration, Congress has appropriated $100 000 to be expended on a Columbus Memorial to be placed at the intersection of Massachusetts and Delaware Avenues, toward the south side of the plaza.

The stone balustrades immediately in front of and along the sides of the east and west carriage entrances to the station were furnished and erected by the E. B. Ellis Granite Company, of Northfield, Vt. The fountains and the balustrades around them were furnished and erected by the Woodbury Granite Company, of Hardwick, Vt. All ornamental ironwork on the balustrades, etc., in connection with the station and plaza, was furnished and erected by the Chicago Ornamental Iron Company, of Chicago, Ill.

The space between the curb line in front of the station and the

FIG. 1.—WASHINGTON TERMINAL STATION: MAIN WAITING-ROOM, DURING CONSTRUCTION.

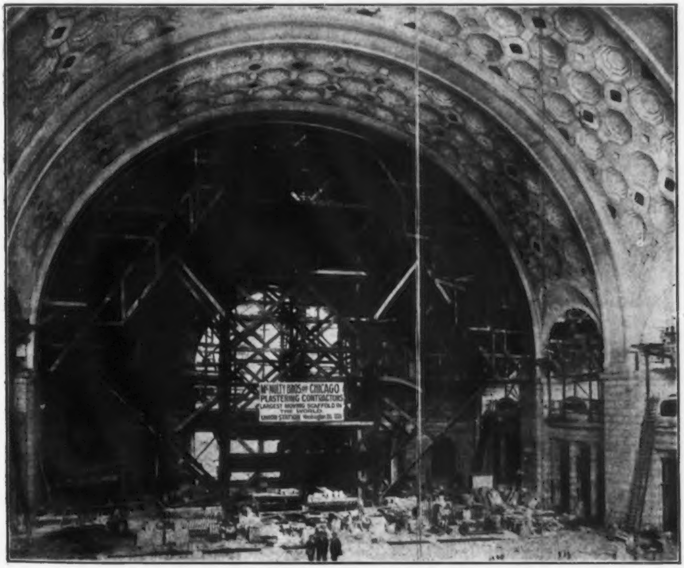


FIG. 2.—WASHINGTON TERMINAL STATION: MAIN WAITING-ROOM, SHOWING TRAVELER USED IN PLACING CEILING COFFERS, ETC.

north side of the central island, including that occupied by street-car tracks, was paved with wood blocks by the United States Wood Preserving Company, of New York. These blocks are 3½ in. deep, and were laid and grouted with hydrolene on a concrete base provided by the Terminal Company. When the plaza fill has completely settled, the remaining roadway space will be paved with sheet asphalt, and the space used exclusively by pedestrians will be provided with cement pavements.

To create the plaza and fill, the streets leading to it required about 750 000 cu. yd. of material, and at least 250 000 cu. yd. were deposited on vacant property in the zone of the Terminal Improvements, bringing it to the elevation of the adjoining streets.

The construction of the terminal station was not entrusted to one general contractor, but separate contracts were made for each branch. This plan was adopted in the interest of economy in construction and because of the magnitude of the undertaking. Propositions were invited from the leading contractors of the country covering the different classes of work, and from the bids thus received the selections were made. In addition to the economical considerations, the company in this way hoped to prevent trouble with unreliable sub-contractors such as are sometimes selected by general contractors. With one or two exceptions, the selections were very satisfactory, and, but for these, this plan would have worked out well. The principal contracts for the building were let in October, 1903.

Foundations and Granite Work.—The contract for foundations and masonry, cut stone, and brickwork was let to the Thompson-Starrett Company, of New York. All masonry below the finished street and plaza grades is of concrete; above these points it is of stone and brickwork. The exterior walls of the head-house and the interior walls of the main waiting-room and ticket lobby are of white granite, from quarries near Bethel, Vt., the only place at present known where granite of this color can be obtained in quantity. The interior partitions and the backing of all exterior walls are of local red brick.

The interior walls of the concourse are finished in white enamel brick with enamel terra cotta trimmings. The walls of the light-wells and the exterior of the arches in the ends of the main waiting-room are faced with white enamel and buff pressed brick. Hard-

burned sewer brick, laid in Portland cement mortar, were used in all arches having spans of more than 16 ft. and in piers for carrying walls and arches. The north wall of the head-house above the junction of the concourse roof is of hard-burned red brick.

The concrete used in the foundations and elsewhere was composed of 1 part Portland cement, 2 parts bank sand, and 4 parts crushed limestone. The mortar used in setting the granite was composed of 1 part non-staining cement, 6 parts slaked lime, and 6 parts white sand. For pointing, the same materials were used, in the proportion of 1 part cement, 1 part lime putty, and 2 parts white sand.

The mortar used in common brickwork was composed of 1 part Portland cement and 3 parts sand tempered with lime paste. For the terra cotta and enamel brickwork the mortar was made of 1 part non-staining cement, 1 part lime putty and 2 parts white sand. The dressed granite ranged from 4- to 8-cut work.

Steelwork.—The contract for the structural steelwork in the station and concourse was let to the American Bridge Company, of New York. As it was essential that the setting of the steelwork and masonry should go on simultaneously, the erection of the steelwork was sub-let to the Thompson-Starrett Company, the masonry contractor. All the interior consists of structural steel and fire-proofing, including particularly the floor and partition construction, and, except where beams and girders are supported on exterior walls, is supported on steel columns carried on concrete foundations.

The steelwork of special note, however, is the roof of the concourse and main waiting-room. The spans of 130 ft. are common to both roofs. The lower chords of the concourse trusses are segmental arches having a rise of 23 ft. The depth of truss is 16 ft. The lower chords of the main waiting-room trusses are semicircular. The trusses are about 20 ft. deep. The trusses in these roofs were erected with a traveler about 40 ft. square and more than 100 ft. high, with booms on the corner posts for raising the load and a small stiff leg on top for guiding it.

Roofing and Sheet-Metal Work.—The roofing, sheet-metal, and skylight work was furnished and erected by J. C. McFarland and Company, of Chicago, Ill. The roofs of the main waiting-room and carriage porch are of reinforced concrete tiles, the roof of the concourse is of reinforced concrete tiles and skylight construction, that

over the ticket lobby is of glass, and the remainder of the area of Ehret's slag roofing. There are skylights at various points in the area covered by slag roofing.

The concrete tile roof construction was built as follows: Reinforced flat tiles, about 30 by 48 by 1½ in., were laid directly on the skeleton steelwork; the entire roof surface was then covered with roofing felt, for the purpose of providing a water-tight surface; light angles, running longitudinally with the structure, were then bolted to the slabs in order to hold the top slabs in place. These slabs are of the same general dimensions and construction, except that at one end they are provided with a projecting lip or overlap and the other end and the sides are raised. The projecting lip overlaps the upper end of the tile below, and the raised edges forming the side joints are covered with a joint cap. Hydrolithic waterproof compound was used in the upper slabs. All flashing and other sheet-metal work is 16-oz. copper, except in the ceiling light construction, which is of galvanized iron.

Plastering.—All plastering in the station, including the cement plaster ceilings of the carriage porch and train tunnels, was done by McNulty Brothers, of Chicago. The scagliola work in the dining-room was also included in the plastering contract, but was executed as a sub-contract by the American Art Marble Company, of Philadelphia. King's Windsor cement was used in the mortar, and, with the exception of the attic and the ceiling of the concourse basement, was executed in three-coat work, the last coat in all cases being plaster of Paris.

The barrel-vaulted ceilings of the main waiting-room, the alcoves on the north and south sides of the same, and the segmental arched ceiling of the concourse, are composed of sunken coffers cast in gelatine moulds, and are suspended from the lower chords of the steel roof trusses by light channel irons and clamps of various forms. With the exception of some plaster ornamentation in the ceilings of the dining- and lunch-rooms, women's and men's rooms, and state apartments, all the work in the other public rooms and offices is plain.

The faces of all piers in the dining-room are finished in scagliola, the predominating color being light yellow. Flanking the main piers, and resting on ornamental bases of verde antique marble, are scagliola columns, the lower portions of which are cylindrical in

section and dark red in color; the upper portions are fluted, and, including the Ionic capitals, are white with veins in imitation of marble. The entire scagliola work was executed in a skillful manner, and finished with a very high polish.

Perhaps the point of special interest, however, and the one which should be emphasized in this paper, was the method of executing the more difficult portions of the plaster work. As stated elsewhere, the ceiling of the concourse is a segmental arch having a span of 130 ft. and a rise of 23 ft. The springing line of the arch is 22 ft. above the floor level of the station and concourse, and the soffit is 45 ft. To execute this work, a light traveler was constructed of sufficient length to extend across the concourse, the top contour of which corresponded approximately with the ceiling curve. It was mounted on small wheels for the purpose of permitting easy movement along the length of the concourse. From this moving scaffold all the ceiling work of the concourse, except the painting of the plaster coffers, was executed.

The ceiling of the main waiting-room is a semicircular or barrel-vaulted arch, the springing line of which is 36 ft. above the waiting-room floor and the soffit 96 ft. It has a clear span of 120 ft. and a total length of 238 ft. To apply the plaster to a ceiling of such proportions of necessity called for a scaffold of unusual size. To avoid the expense of erecting a new and costly traveler, the one used by the Thompson-Starrett Company in the erection of the structural steel was obtained. This structure was originally about 40 ft. square and more than 100 ft. high. To make it available for the purpose, the top section was removed and wings about 40 ft. wide were built on the sides. This produced a traveler about 40 ft. deep and of a width equal to the span of the room. The top contour of the wings consisted of a curve approximating the curve of the ceiling. The large plaster coffers or panels were raised to the top of this traveler by hoisting engines, from which point to the ceiling they were handled by workmen. With this equipment, and a large casting and modeling force, excellent progress was made.

Carpentry and Hardware.—The Meader Furniture Company, of Cincinnati, Ohio, furnished and erected in place all woodwork, supplied all hardware, and did all the painting and finishing of woodwork and plaster in the entire building, with the exception of the painting and decorating of the public rooms, which was done by

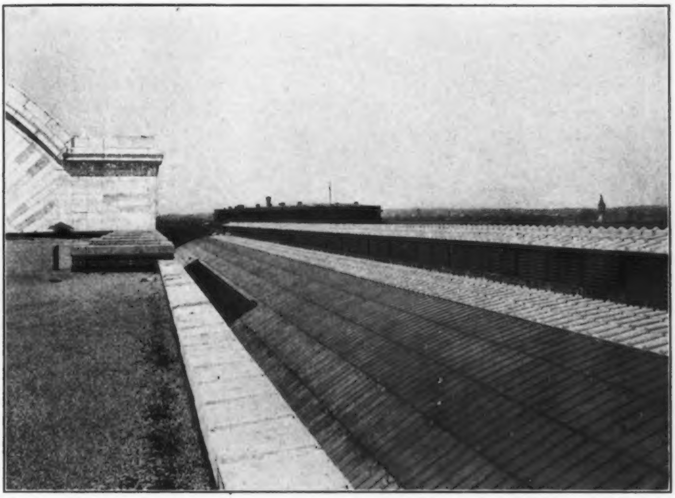


FIG. 1.—WASHINGTON TERMINAL STATION: ROOF OF CONCOURSE.

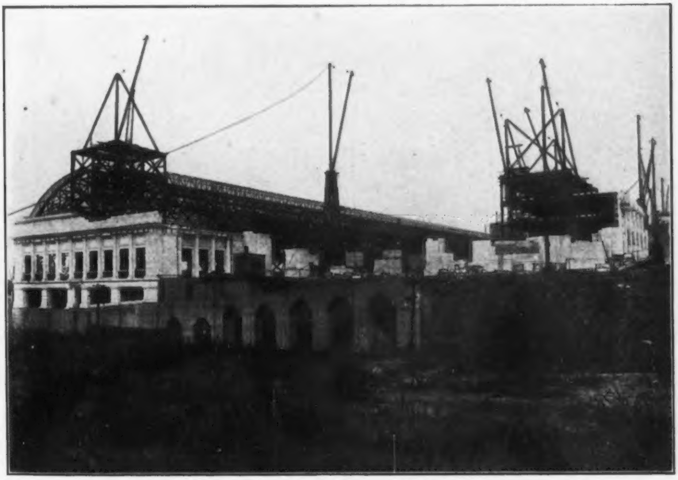


FIG. 2.—WEST END OF WASHINGTON TERMINAL STATION, SHOWING ERECTION OF LAST STEELWORK IN CONCOURSE ROOF.

Joseph F. Sturdy, of Chicago, Ill. The woodwork included all interior and exterior door frames and trims, window frames, sash, and trims, wardrobes, and floors, except where marble and cement were used, and all centers and templets for masonry and terra cotta work.

It also covered the settees for all waiting-rooms, certain cases in the ticket-offices, cases for the storage of supplies, etc., in the ticket-agent's office, and all furniture and fixtures in the ticket-receiver's office and conductors' workroom, except the tables and desk. The settees in the waiting-rooms are of mahogany, from designs furnished by D. H. Burnham and Company, the architects. Mahogany was also used in all interior and exterior doors and interior trim on the main floor. All interior woodwork above the first floor was birch finished in mahogany. All floors were laid with first-quality clear maple.

The painting included all outside and inside woodwork, and outside and inside structural iron except that covered by the ornamental iron contract, together with the painting of all plaster work except as above noted. The plaster work in the baggage checking-room, toilet-rooms, barber shop, and office entrance lobbies on the first floor, and all corridors and toilet-rooms on the second and third floors, were finished with one coat of hard oil and three coats of pure white lead and linseed oil, in light yellow. All other plastered surfaces were painted with one coat of hard oil and tinted in light yellow with the best quality of calcimine. Inside and outside metal-work, except copper, received one coat of mineral paint and two coats of linseed oil and white lead. This includes all exposed pipes, with the exception of steam pipes, which were taken care of by the heating contractor.

All hardware is of No. 2 statuary cast bronze metal, except springs and checks, which are of iron finished to match the hardware. The hardware in toilet-rooms, etc., is nickel-plated. All hardware included in the above contract was furnished by P. and F. Corbin and put in by the Meader Furniture Company.

Cement Work.—The concrete and cement work in the floors of the concourse, the corridors of the main building, the basement baggage-room, and the sidewalks along the front and ends of the station, were constructed by the Rudolph S. Blome Company, of Chicago, Ill. The concourse floor was laid in design; the body was of the usual Portland cement color, and the ornamental portion was colored red by the

use of mortar stain. The corridor floors were also laid in design, the ornamental portion consisting of a red border.

The floor of the basement baggage-room and the sidewalks along the front and ends of the building were constructed according to the usual practice, 6 in. in thickness, and laid on a 6-in. bed of cinders. The edges of all sidewalks around the building and the edges of floors around teaming spaces are protected with angle-iron curbs, consisting of 6-in. angles laid with one leg vertical, forming the edge of the platform or walk and secured to the body of the sidewalk by iron clamps. The top finish of all sidewalks and floors consists of 2 parts Portland cement and 3 parts torpedo sand.

The asphalt pavements in the east and west basement driveways and in the east court and carriage porch at the west end were included in the above contract, but executed by the Cranford Paving Company, of Washington, D. C., as sub-contractor. The original specifications for asphalt roadways provided for the use of European asphalts (Seyssel, Neuchatel, etc.), but, owing to their brittleness, and to delay in securing them, it was considered advisable to substitute Trinidad, and the contract was changed accordingly.

Marble Work.—All marble work, except the basin slabs and backs furnished by the plumbing contractor, was furnished and set in place by the Vermont Marble Company, of Proctor, Vt. The floors in the main waiting-room and ticket lobby are of 24-in. white-cornered tile with 6-in. red Champlain dots; those in the men's smoking-room and the women's waiting-room are of 15-in. white tile with 3-in. red Champlain dots; and those of the toilet-rooms, baggage checking-room, telephone-room and drug store are of 12 by 24-in. plain white tile.

The floors in the dining- and lunch-rooms and the barber shop are of 12-in. white tile; those in the state reception rooms are of 12-in. white tile with 3-in. red Champlain dots at intervals of 24 in. The floors of the entrance and exit vestibules are in designs using Glen Falls black, verde antique, red Champlain, and Vermont white. All white tile floors above mentioned, together with risers, treads, and landings of stairways, are of white Vermont marble. All partitions, backs and stiles in toilet-rooms, and trim of smoking-room and office entrances are of light cloud Vermont.

Verde antique is used as a base around the walls of the dining-room

and as bases for the scagliola columns. All marble work in the toilet-rooms is supported on and held in place by nickel-plated brass rails, angles, braces, etc.

Sewerage, Drainage, and Plumbing.—The Wells and Newton Company, of New York, furnished all labor and material required in the construction of all sewers and drains, the installation of all piping for cold, hot, and drinking-water systems, and the setting of all plumbing fixtures and appurtenances.

The pipes for carrying wastes of all kinds, laid under ground, are of cast iron, and, except where used in connection with wrought iron, were coated both inside and out, while hot, with coal-tar varnish. All suspended pipes for carrying wastes are of galvanized wrought iron, supported, at intervals of not more than 12 ft., from the beams of the floors below which they are carried.

All cast-iron pipe is standard-weight gas, cast on end, in lengths of 12 ft., with inner and outer surfaces concentric, sound, and free from all defects; and all fittings were made with special reference to the uses to which they were to be put. All wrought iron is galvanized, and of standard weight and dimensions. The fittings were of cast or malleable iron, as the needs suggested.

Brass pipe and fittings are used in the hot- and cold-water systems, and copper pipe and fittings in the drinking-water system. In addition to the granite drinking fountains in the main waiting-room, there are marble fountains in the women's waiting-room and in the smoking-room, and vitreous fountains in the office corridors, all connected with the drinking-water system.

All risers and concealed branches for soil, waste, down-spouts, and trap ventilation are of galvanized wrought-iron, Y-connections being used on all water and waste pipes. There are plugged openings on all water, vent, and waste risers at each floor, in addition to the connections necessary for fixtures already installed. There are hand-holes with screw-plugs on all branches at the connections with risers and on all risers at connections with sewers.

All pipes which pass through the roof are flashed with sheet lead, extending not less than 8 in. in all directions from the pipes, and lead soil pipe, $\frac{1}{8}$ in. thick, was placed around each pipe, extending from the sheet lead to the top of the pipe and turning down 1 in. inside. The sheet lead and pipe are joined by a wiped joint.

The house water supply is obtained from four steel tanks of $\frac{3}{8}$-in. material in the attic, each having a capacity of 5 000 gal. below the overflow line. Each tank has a flanged steel drip-pan of $\frac{5}{16}$-in. metal, 4 in. deep and 1 ft. larger in diameter than the tank. Each tank has cast-iron pipe flanges of proper sizes for overflow, equalizing, and discharge pipe connections, and each drip-pan has a 1-in. drain connection. The tanks and pans received two coats of red lead before assembling and two coats of galvanic varnish inside and out after they were in place.

All hot-water, cold-water, soil, and waste pipes are covered with a double layer of wool felt, lap-jointed with insulating paper, with two coats of water-proof paint, and protected by canvas treated with two coats of water-proof paint not acted on by cement or mortar. All pipes in the baggage-room, or other rooms not provided with heat, are covered, in addition to that above noted, with two 1-in. layers of hair-felt alternating with layers of tar-felt, all lap-jointed and protected with water-proof paint.

All exposed pipes in the ceiling of the train tunnel are covered with a double layer of air-cell covering, protected with canvas impregnated with fire- and gas-proof paint, in addition to the covering specified for condensation. The drinking-water pipes are covered with cork $2\frac{1}{2}$ in. thick, bound with No. 18 galvanized wire, and finished with hot asphaltum.

All the toilet-rooms are equipped with siphon-jet, "Columbia," water-closets, made by the Standard Manufacturing Company; they have dark mahogany seats, and the cisterns, where concealed, are of plain wood, lined with copper, and supported on galvanized-iron brackets secured to the marble backs or to the walls. Each cistern is connected with the bowl by a $1\frac{1}{4}$-in. rough brass flush pipe in the rear of the marble back, and a nickel-plated connection with the bowl in front of the marble. Where closets are set without casings, the tanks are of dark mahogany and are supported on nickel-plated brackets.

Vitreous porcelain-lipped urinals, made by Haines, Jones, and Cadbury, are placed in the marble urinal stalls of all toilet-rooms. These urinals have traps formed in the bowls, and are constructed so that the flush and drain pipes connect from the rear through the marble backs of the stalls. They are flushed by plain wood copper-lined cisterns supported on galvanized-iron brackets, and connected with a concealed

water supply. In all cases several urinals are connected to each cistern; in no case, however, are more than four connected to a 3-gal. tank. The wash-basins, slop-sinks, bath-room equipments, etc., were furnished by the same firm. The basins are set in marble slabs supported on nickel-plated legs and standards; in no case, however, are more than three basins set in one slab where basins are set in batteries. The basin cocks are of the self-closing type, manufactured by the Federal Company, of Chicago, and are connected to the hot- and cold-water supplies with ½-in. nickel-plated brass pipe. There are key stops in the hot- and cold-water supplies leading to each basin.

The slop-sinks are enameled-iron, combination trap, standard, 20 by 22 by 12-in., with nickel-plated brass flushing rim, strainer, and double compression, combination flush and supply faucet and supply pipes to the floor. The bath tubs are 5½-ft., enameled iron, with zinc-white finish outside. The shower and needle baths are nickel-plated brass, with all fixtures complete. The faucets in the public drinking fountains are special, made from designs by the architects.

As stated elsewhere, the general marble work in all toilet-rooms was put in by the Vermont Marble Company. The basin slabs, backs, aprons, and sides, where required, were furnished and erected by the plumbing contractor, blue-veined Italian marble being used. The slabs for single basins are 1¼ in. thick, and for more than one, 1½ in. thick, and not less than 22 in. wide.

There are two electric bilge pumps in a pit in the sub-basement for the purpose of draining the sub-basement and the elevator pits, each pump being enclosed in a water-tight tank and capable of lifting 50 gal. per min., about 20 ft. to a basement sewer.

Heating and Ventilation.—The heating and ventilating systems were installed by the Wells and Newton Company, of New York. The entire building except the main waiting-room, ticket lobby, and vestibules, is heated by a two-pipe, low-pressure, direct-steam system. The main waiting-room and ticket lobby are heated by indirect radiation, fresh air being drawn through nests of steam-heated coils and forced to these rooms by fans. After passing through the coils, and before entering the fan chamber, the air is conducted through air-washers, in order to remove dust and other impurities.

These devices consist of large drums, with sheet-metal heads and wooden-frame bodies, covered with burlap. Beneath these drums

there are shallow copper-lined tanks with automatic water supply and overflow connections. When in operation, the circumferences of the drums revolve through the water in the tanks, forming a thin film of water in the mesh of the burlap. The air, in entering the fan chamber, is obliged to pass through the burlap covering of the drums. In doing so, the impurities are removed by the film of water. At each revolution the dirt collected is washed from the burlap and deposited in the tanks.

The fans which force warm air into the main waiting-room and ticket lobby are operated by 40-h.p., 200-volt, 3-phase, 60-cycle, constant-speed, Westinghouse, induction motors, at a speed of 840 rev. per min. The air-washers are operated by 2-h.p., 200-volt, 3-phase, 60-cycle, Westinghouse, induction motors, making 1 700 rev. per. min. The coil and mixing chambers, air-washer rooms, and fresh-air intake are of No. 18 galvanized iron with heavy angle-iron frames. The fresh-air intake may be closed with a balanced sheet-iron damper when not in use.

The vestibules are heated by both direct and indirect radiation. There are two radiators, connected with the two-pipe, low-pressure, direct-steam system, in each vestibule, except the east and west ones of the group leading to the concourse, in which there is only one each. In addition to the radiators, connection is made with the fan system used in heating the main waiting-room and ticket lobby. There are also ten ventilating fans in various parts of the building. Seven of these are in the attic of the east end for ventilating the serving-, dining-, and lunch-rooms and the toilets in the east end of the building. Six of them are operated by 2-h.p. motors, the seventh by a 3-h.p. motor.

For ventilating the kitchen and other service-rooms attached to it, there is one fan, operated by a 10-h.p. motor on the floor above. One fan, operated by a 5-h.p. motor in the basement, ventilates the emigrants' waiting-room and toilet in the basement, and the employees' toilet at the east end of the concourse. One fan, operated by a 5-h.p. motor in the attic near the elevator shaft, ventilates all toilets in the west end of the building.

All motors for the ventilating fans are of the Westinghouse induction type, designed for a 200-volt, 3-phase, 60-cycle current. The motors operating the fans for the kitchen and toilet-rooms at the

west end have speeds of 1 120 rev. per. min.; all others have speeds of 1 700 rev. per. min. The capacities of these fans range from about 6 000 cu. ft. per min. for those operated by 2-h.p. motors, to 75 000 and 80 000 cu. ft. per min. for those operated by the 40-h.p. motors.

The entire building is heated by exhaust steam from the main power-house brought to the station through the main steam supply pipe in the tunnel in the west wall. The pipes in the station are supported from the main floor-beams, at intervals of about 12 ft., by expansion hangers. All risers are connected at the tops of the supply main, are provided with gate-valves, and are anchored at the main floor line in such a way that all expansion shall be upward. Steam return lines take care of condensation.

Although the system is designed to circulate steam at low pressure, it is the intention to have it circulated at atmosphere or below. This is accomplished by a Warren-Webster vacuum system, the various sub-divisions on the heating system having corresponding sub-divisions on the vacuum system. By this arrangment one portion of the system can be closed for repairs, etc., without interfering with the others.

Two 18 by 16 by 16-in. pumps, manufactured by the Knowles Steam Pump Company, return the condensation to the power-house. A 6 by 4 by 4-in. Deane pump takes care of the condensation from the kitchen. Hot water for use throughout the building is furnished by two Toby heaters in the basement.

All radiators are of the American Radiator Company's make, of plain unveiled steam pattern, and are controlled by thermostats put in by the Johnson Service Company. All radiators are connected through the two-pipe system, and graded down from supply risers to return risers, with connections set so as to prevent trapping by the expansion of the risers. Brass shields have been placed between all radiators and the adjacent walls on the first floor.

All pipes in connection with the heating system are covered with moulded asbestos sectional covering, protected by 8-oz. canvas with two coats of anti-flame paint tinted to harmonize with the decorations in the various rooms. The Toby heaters are covered with moulded asbestos blocks, ½ in. thick, supported on ½-in. mesh wire netting, a 1-in. air space being provided between the covering and the heater. All steam pipes in portions of the building not heated are

covered with alternating layers of tar-felt, hair-felt, and insulating paper, and protected by canvas having two coats of water-proof paint. The exposed pipes in the train tunnel have a double covering of air-cell, protected by canvas and water-proof paint.

Fire-Proofing.—The fire-proofing or hollow tile work in the station was furnished and set in place by the National Fire Proofing Company, of Pittsburg, Pa. As stated elsewhere, all the floor and roof construction is supported on steelwork consisting of girders and I-beams spaced at intervals of from 4 to 5 ft. on centers. The spaces between these beams are filled with hollow tile arches, generally of segmental form, though some flat arches were used. All skewbacks are of such form as to furnish support for the soffit tiles immediately beneath the lower flanges of the beams. All partitions and corridor walls are formed of tiles, and all columns not encased in brickwork are protected by the same material.

The fire-proofing was set in lime mortar tempered with Portland cement. It may be interesting to note that all the fire-proofing was obtained from the terra cotta works a few miles west of Washington, and was very satisfactory in quality.

Glazing.—The Pittsburg Plate Glass Company furnished all the glass, and did all the glazing except in the skylights and ceiling lights placed in connection with the sheet-metal work in the station building. All exterior glass above the first floor is double-thick, the remainder is polished plate. Plate glass, either clear or chipped, was used for all interior work in the basement and first floor. In the second and third floors crystalline plate is used below the transom line, and double-thick above. The attic glass is all double-thick. There are plate-glass mirrors in the lavatories, barber shop, and toilet-rooms. All glass not held in place by metal or wood is set in putty and secured by glaziers' tacks.

Decorations.—The general painting of plaster and woodwork throughout the station was done by the carpentry contractor. This applied to all work above the first floor and to the wood and plaster work in the private rooms on the main floor. The painting and decorating of the public rooms, however, was done by Joseph F. Sturdy, of Chicago, Ill. The ceiling of the main waiting-room and the alcoves on either side are painted in oil, the color being a light gray, to harmonize with the masonry side walls; the centers of the

sunken panels are picked out in gold leaf. The ribs introduced in the ceiling at intervals of about 40 ft. and the arch at the west end of this room are also decorated in gold leaf.

The decorations of the dining-room are detailed from the best examples of Pompeian work. The panels in the alcoves are covered with evenly-woven tapestry burlap painted in oil and ornamented. The center panels are dark red and the side panels dark green; both are finished with ornaments in yellowish brown. The ceiling beams and clerestory walls are covered with decorators' canvas painted in oil in light yellow with ornaments in reds and greens. The enrichments of plaster are gilded with gold leaf and picked out in harmonizing colors.

The paneled surfaces in the lunch-room are covered with tapestry burlap painted in oil and decorated with Pompeian ornament. The ornamental plaster is gilded with gold leaf, lacquered with French lacquer where necessary to obliterate glitter. The general color scheme in the walls of this room is quite different from that in the dining-room as the colors are much lighter, the prevailing tone being light yellow, except that the panels are of a deep brownish yellow with corresponding contrast in ornaments. The coloring of the ceilings and clerestories of the two rooms, however, is very similar.

The panels in the side-walls of the women's room are covered with tapestry burlap painted in designs in greens and browns. The plaster ornaments are picked out in gold leaf. The ceiling is covered with decorators' canvas painted in oil and divided into panels by the use of a light green border treatment with the light cream body of the ceiling.

The general decorative treatment in the smoking-room is smiliar to that in the women's room above described, except as to color. The ceiling of the ticket lobby is painted in light gray, including the plaster and the metal ceiling light frames. The ceiling in the concourse is painted in oil, the color being light cream.

The ceiling of the state reception-room is covered with decorators' canvas, the walls with tapestry burlap, both painted in oil. All moulded work and ornamental plaster is painted in oil. Caps and enrichments are finished in gold leaf. The arched panels in the west side of the room are decorated with conventional ornament in green and brown. The small panels in this wall are worked in tapestry

design in soft colors, toned to produce a soft subdued effect. The large panels are gilded with aluminum leaf and decorated with a fret border about 6 in. wide, designed so as to avoid stiffness. The prevailing colors in this suite of rooms are brown, dull gold, brownish blues, and soft reds, interwoven so that no one color asserts itself.

Terra Cotta.—All exterior masonry and the interior walls and piers of the open porticos are of granite. The domes of the central and end pavilions, the loggias connecting them, and the east portico are of terra cotta, the texture and color being made in imitation of the surrounding granite. The section of the hemispherical dome above the door leading to the state apartment is also of terra cotta with color and texture as above, but with an entirely different architectural treatment.

The interior walls of the concourse are lined with white enamel brick, with base, window and door trims, and cornice of enamel terra cotta of the same color. The lintels and sills of windows opening on the light courts, the copings on the tops of all brick walls carried to the roof line, and the architectural features in the baggage checking-room walls are of semi-glazed terra cotta in colors to harmonize with the adjoining brickwork. The settings for two of the clocks on the concourse and the large clock in the main waiting-room are also of terra cotta, in color to suit the adjoining masonry. The terra cotta was furnished and erected complete by the Atlantic Terra Cotta Company, of New York.

Ornamental Ironwork.—All ornamental iron and bronzework was furnished and erected by the Chicago Ornamental Iron Company, of Chicago, Ill. The ornamental cast-iron work was made from the best brands of soft Superior and Southern pig irons, and includes the train fence on the concourse and all ornamental ironwork on the outside walls of all structures on the concourse, the metal-work holding the glass in the windows of the main waiting-room, a portion of the metal-work in the stairs, and the grilles used in connection with heating and ventilation. It also includes the cast-iron doors for electric cut-out boxes, pipe shafts, and dumb-waiters.

The ornamental wrought-iron work includes the balustrades of the stairways and stairwells, the stringers supporting the stairs and platforms, the wrought-iron wind bracing in the large windows of the main waiting-room, the grilles in the elevator enclosures, the rolling

shutters at the east and west concourse basement entrances, window guards, gas-pipe railings, baggage chutes, and the boiler-plate guards around columns in the baggage-room.

All fine ornamental iron castings were made in stove-plate moulding sand. All ornamental details were specified to be moulded in clay and then cast direct from the plaster reproduction of the clay model, instead of from wooden patterns. All ornamental ironwork on the stairways, except railings and balustrades, is painted black, the railings, balustrades, elevator enclosures, and ornamental iron in the elevator cabs are finished in Bower-Barff.

The bronzework covers the thresholds in openings where ornamental iron frames are used, kick-plates on doors of public rooms of the station, the bronze grilles in the ticket-office, and the bronze racks in front of the ticket-office windows.

Miscellaneous Facilities.—Attention is now called to the details of the general telegraph office, the telephone exchange, the telautograph systems, rest and recreation quarters for the trainmen, the cleaning system, the clock system, U. S. Mail facilities, and the equipment of the dining- and lunch-rooms, kitchen, serving-room, etc.

Telegraph Service.—The telegraph lines from the north and south are brought to the station through underground terra cotta and fiber ducts, the duct system extending as far north as the north side of New York Avenue and south to the south portal of the First Street Tunnel. The ducts north of the station are laid in a concrete cradle in a trench between the tracks, those south in the masonry walls of the tunnel. There are manholes at intervals of 300 or 400 ft. throughout the system.

The terminal-rooms, where the cables terminate and the building wires begin, are in the basement. One room contains the Baltimore and Ohio Railroad and the Western Union wires, the other the Pennsylvania Railroad, Postal, and Washington Terminal wires. There are two motor-generator sets for supplying 60-volt, direct current for use in the operation of the Pennsylvania Railroad wires, and two sets for supplying 6-volt, direct current for use in the operation of the Washington Terminal local wires. These currents are stepped down from the 220-volt alternating current of the power circuit.

The general telegraph office is on the third floor at the east end of the station, and is equipped with a 50-jack-board and three tables.

The jack-board is capable of taking care of 50 loops or 100 single wires. There are now 32 loops in operation, 6 leading to "A" tower, at the north entrance to the tunnel, 10 leading to "K" tower, in the throat of the train yard, and 16 to "D C" office, on the concourse adjacent to the station-master's office. Communication with "C" tower, at the throat of the coach yard, is established by direct connection with the main-line wires at that point.

Each table has 8 instruments and 2 jack-boxes, the equipment being sufficient to accommodate 24 men in case of emergencies. Connection is made in the station with the Western Union and Postal wires, so that in cases of necessity they can be pressed into service.

Telephone Service.—The Chesapeake and Potomac telephone cables enter the terminal property at H Street, from which point to the terminal-room in the station they are carried through the fiber ducts of the telegraph conduit system. The terminal-room is in the basement adjacent to the telegraph terminal-rooms, and contains, in addition to the Chesapeake and Potomac wires, the wires of the Terminal Company and the police and fire-alarm lines leading to the police and fire-call boxes at the station.

The exchange is adjacent to the telegraph office, and contains a four-position board capable of taking care of about 300 branches. Branches have been run from this board to all parts of the terminal property and joint coach and engine yard, 95 having been installed to date. In addition to the branches above noted, trunk-line wires belonging to the Pennsylvania Railroad Company are connected with the above board as follows: One each to Baltimore, Md., Wilmington, Del., and Philadelphia, Pa.; two to the Potomac freight yard near Alexandria, Va.; two to the P. B. & W. freight yard exchange at 4½ Street and Virginia Avenue, and one to the city ticket-office.

A motor-generator set furnishes ringing current for the telephones in case of failure at the main telephone office. There is also an 11-cell storage battery, for use with the telephone system, and for operating the motor-generator.

Telautograph System.—On account of the size of the terminal station and train yard, and the consequent distance between the various offices, prompt communication would have been impossible without some system less troublesome than the telephone or telegraph. To meet this condition, the Gray National Telautograph Company, of

New York, furnished and put in two separate systems, one for reporting from "K" tower the time of arrival of trains, the other for communication between the dining-room, serving-room, and kitchen.

There is a transmitter and pilot receiver in "K" tower, and connected with it there are three receivers on the train fence, one in the bureau of information, one in the station-master's office, one in the baggage-room, one in the inspectors' room for the low-level tracks, one in the Adams Express office, and one in the United States Express office. Later, an additional transmitter was placed in the station-master's office and connected with all receivers, for the purpose of augmenting the service by giving additional information through the station-master's office. When one transmitter is in use the other is locked in such a way as to prevent disturbance. The operator at "K" tower obtains telegraphic advice regarding the movements of in-bound trains. The reports are then transferred to the transmitter in the operator's handwriting, and at the same instant copies of the report appear at all the receivers on the system.

In the dining-room, orders are transferred to the transmitter, and, as they are written, copies appear simultaneously at the receivers in the serving-room and kitchen, thus insuring quicker service and fewer mistakes.

Comfort and Convenience of Employees.—One of the most attractive features in this terminal is the provision made for the comfort and convenience of men whose duties require them to enter and leave the terminal at all hours of the day or night. To meet this need, more than 20 000 sq. ft. of floor space in the upper floors of the east end of the station have been set aside for the use of employees, and arranged as reading-room, social hall, assembly-room, bowling-alleys, gymnasium, and sleeping quarters.

The furniture and equipment necessary to fit up these quarters was provided by the Terminal Company, but, to make the department semi-self-supporting, a nominal charge was fixed for facilities afforded. and the management was placed in charge of the Railroad Young Men's Christian Association. The charges are as follows: Membership fee $5 per annum; use of beds, 10 cents per night; use of lockers, 50 cents and $1 per annum. A nominal charge of about half the regular price is made for the use of pool and billiard tables and

bowling-alleys. All other privileges, including baths and athletic features, are free to members.

The baths consist of tub, needle, and shower, and are maintained in exceptionally cleanly and sanitary order. The sleeping-rooms are equipped with iron cots, with good springs and mattresses. All facilities are open day and night, and the men are called at any hour they may designate, a clerk being continuously on duty for that purpose. The sleeping-rooms were removed as far as possible from the recreation and social rooms, so that the occupants' rest would not be disturbed by noises. The reading-room is supplied with daily, weekly, and monthly periodicals, covering all classes of reading. There are on the tables at this time about 35 daily papers, 30 weekly, and 37 monthly magazines.

Cleaning System.—The Dunn-Locke Vacuum Cleaning Company, of New York, placed in the basement of the station building a plant for cleaning and scrubbing the floors of the offices and public rooms in the station and concourse. It consists of two steam-driven air pumps having cylinders 9 by 22 in. with a stroke of 12 in., each having a capacity to operate 16 renovators at one time from any 16 outlets.

From the suction outlets of the saturating chambers of the vacuum machines, in the basement under the east end of the main waiting-room, there is a 4-in. galvanized main header line, to which each of the ten vacuum risers in the head-house proper, put in by another contractor, is connected. A connection is also made with the lines under the concourse floor. The exhaust line is connected with the heating system of the station. There are eight separate water lines in connection with this system, six on the concourse and two in the general waiting-room.

The plant discharges directly into the sewer, thus avoiding the necessity of cleaning the collection tanks. On all floors throughout the station there are $\frac{3}{4}$-in. connections with the various risers, and 1-in. connections on the concourse.

The equipment furnished with this plant consists of 600 ft. of 1-in., non-collapsible, steel-ribbed hose, in 50-ft. lengths, for use on the concourse; 600 ft. of $\frac{3}{4}$-in., non-collapsible, steel-ribbed hose, in 50-ft. lengths, for the interior of the station; twelve carpet renovators; twelve bare-floor renovators; twelve renovators with mop; twelve

4-in. hand renovators for tapestry, furniture, etc.; twelve rubber-corner renovators; twelve 4-in. hard brushes for woodwork; twelve 8-in. wall brushes with short handles; and twelve 3-piece extension tubes.

Clock System.—The Magneta Company, of New York, installed in the station and concourse a clock system known as the Magneta electric, consisting of a master-clock and ten secondary clocks. The master-clock is in the telegraph office on the third floor of the station. It is wound by an electric motor, the current for operating it being obtained from the main power-house. It is of the standing type, with mahogany case, and has a self-winding device and a Reifler compensation pendulum.

Of the secondary clocks: there is one at each end of the concourse, each having a 5½-ft. dial; one over the station-master's office in the center of the concourse, with a 2¾-ft. dial; one in the transom space over the middle door between the ticket lobby and the carriage porch, having a 3 ft. 2-in. dial; one over the marble mantle in the smoking-room, with a 2¾-ft. dial; one in the east end of the baggage checking-room, having a 5-ft. dial; one in the east end of the main waiting-room, with a 6½-ft. dial; one in the east end of the women's waiting-room, with a 3-ft. dial; one in the west end of the dining-room, with a 3½-ft. dial; and one in the west end of the lunch-room, with a 3 ft. 7-in. dial.

The settings for all the secondary clocks are special, and were made from the designs of the architects. The architectural treatment of the settings is in harmony with the surroundings. The clocks on plaster walls are set in plaster trims. Those used in connection with ornamental iron are set in frames of that material. The smoking-room clock is set in the marble trim above the mantel in a bronze frame. The large clocks in the east and west ends of the concourse and in the east end of the main waiting-room are set in ornamental terra cotta.

All secondary clocks have standard electrical movements, and are actuated by the master-clock, which not only operates the dials but keeps them synchronized at all times. All clocks are operated on half-minute intervals.

Mail Chutes and Boxes.—The Automatic Mail Delivery Company, of New York, furnished and put in two mail chutes with collection boxes in the office entrances, two collection boxes on pedestals in the main portico, and two collection boxes on the concourse, supported

on brackets attached to the north wall of the head-house. The chutes are of glass and sheet metal held together with metal frames and ornamental mountings, supported in position by angle irons attached to the building construction.

The chute in the east office entrance extends from the collection box on the main floor to a point about 4½ ft. above the fourth or attic floor; that in the west entrance extends to a point 4½ ft. above the third-story floor. The entire equipment is in bronze. The two boxes at the bases of the chutes in the office entrances are finished in Bower-Barff, to harmonize with the ornamental ironwork of the stairways and elevator enclosures, the remainder in antique brushed brass.

Cab Service.—In order to have all facilities up to the standard of convenience inaugurated in the construction of this terminal, a taxicab service was established by the Terminal Taxicab Company to replace the cab service operated by horses at the old stations. This company operates its cabs under a contract with the Terminal Company, paying for its concession a percentage of its receipts, the same as other companies or individuals holding concessions in the station. To some extent, the Taxicab Company bears the same relation to the Terminal Company that the horse-cab service did to the railroad companies, in that its operation on the terminal property is controlled by the Terminal Company.

Dining- and Lunch-Room Equipment.—The counter and stools, cashier's desk, and oyster-shucker in the lunch-room were supplied and erected in place by William Grey and Sons, of Philadelphia, Pa. The furniture in the dining- and lunch-rooms, consisting of a checker's desk, 24 serving tables, 44 dining and lunch tables, and 236 dining chairs, was supplied by the A. H. Andrews Company, of Chicago, Ill.

The lunch counter and cashier's desk have galvanized-iron frames, verde antique counter tops and bases, and light cloud Vermont dados, the former having a bronze foot-rail. The oyster-shucker has nickel-plated legs, and is of light cloud Vermont marble. The 57 stools for the lunch counter have bronze standards and mahogany seats, the base being anchored to the marble floor. All furniture in the lunch- and dining-rooms is of mahogany, upholstered in Spanish leather.

Kitchen, Store, and Serving-Rooms Equipment.—The shelving, tables, lockers, wardrobes, dish-racks, etc., in the kitchen, storerooms, and service-rooms of the station, and the wire-mesh partitions and

window screens for these rooms were furnished by the Wayne Iron Works, of Philadelphia, Pa. The former equipment is of sheet metal, the latter is of galvanized-iron wire with channel-iron frames.

The kitchen, storerooms, pastry-room, butcher shop, etc., are on the second floor, immediately over the state suite, and the serving-rooms are on the main floor, adjoining the dining- and lunch-rooms. These rooms have been supplied with the latest and most improved cooking apparatus and fixtures by the Duparquet, Huot and Moneuse Company, of New York, the equipment being sufficient to supply the crowds for which Washington is frequently required to cater.

Refrigerators.—Refrigerators for the dining- and lunch-rooms, serving-room, and kitchen were furnished and erected by the Lorillard Refrigerator Company, of New York. The entire system comprises 27 refrigerators of various sizes distributed throughout the restaurant layout, including the east basement, lunch-room, serving-room, storerooms, and kitchen, as shown in Table 1.

TABLE 1.—REFRIGERATORS IN WASHINGTON TERMINAL STATION.

Number of refrigerators.	Consecutive number.	Name.	Dimensions. Length.	Dimensions. Width.	Dimensions. Height.	Capacity in Cubic feet.	Number of coils.	Temperature, in degrees, Fahrenheit.
			ft. in.	ft. in.	ft. in.			
1	1	Cold Storage, A. " " B.	25 6	23 3	11 0	6 521	4 8	34° 28 to 40
1	2	Fish	4 0	3 0	3 4	40	1	34
1	3	Baker's	5 0	3 6	7 0	122	1	38
1	4	Order	5 0	3 6	7 0	122	1	34
1	5	Salad	6 0	3 0	2 6	45	1	40
1	6	Serving pantry	10 0	3 6	7 0	245	2	38
1	7	Milk and cream	16 9	2 9	3 2	145	1	38
1	8	Ice cream	......	......	......	....	1	8 to 10
1	9	Buffet	14 0	3 0	3 1¼	140	3	32 to 38
1	10	Oysters	5 0	3 6	7 0	122	1	36
3	11	Milk	2 3	1 5	2 9	....	No coils	....
3	12	Butter	2 9	1 3½	2 9	....	" "	....
3	13	Cream	2 2	1 5	2 9	....	" "	....
1	14	Milk	3 0	3 0	3 6	....	" "	....
1	15	Butter	3 0	1 6	3 6	....	" "	....
1	16	Cream	3 0	2 0	3 6	....	" "	....
1	17	Milk storage	5 ft. 10 in. front, 4 ft. 6 in. right end, 5 ft. 0 in. left end, 8 ft. 0 in. high			210	2	34
1	18	Ice cream storage	6 2	3 4	2 10	58	1	8 to 10
1	19	Ice storage	16 6	8 0	8 0	1 056	1	32
1	20	Garbage	10 7	10 0	8 0	840	3	28
1	21	Caraffe freezer	12 0 raised on 10 in. bearers, making 10 ft. 0 in. over all	7 0	9 2	770	20	To suit

Refrigerators Nos. 11 to 16 are cooled with ice, the others with coils connected with the brine system of the refrigerating plant. The walls of Nos. 1 to 8 and 17 to 20 were constructed as follows: Exposed outer sheathing of ash, "ship finished," layer of water-proof paper, tongued and grooved spruce running in the opposite direction to the outer sheathing, layer of water-proof paper, boiler hair-felt, layer of water-proof paper, tongued and grooved spruce running longitudinally, layer of water-proof paper, and inner sheathing of tongued and grooved spruce running vertically.

The front of Refrigerator No. 1, in the butcher shop, was furred and wire-lathed, but plastered by another contractor, the doors and frames being set forward to compensate for the thickness of the lath and plaster. The construction of Nos. 9 and 10 was similar to those above described, except that mahogany, finished and paneled to match the surrounding woodwork, was used for the exposed outer sheathing. No. 21 was constructed of two sheathings of spruce and water-proof paper, and a layer of hair-felt 1½ in. thick, in addition to the wall construction of the above refrigerators. Nos. 11 to 16 were constructed as follows: Exposed outer sheathing of mahogany, finished and paneled to match the trim of the surrounding woodwork, layer of water-proof paper, boiler hair-felt, layer of water-proof paper, inner sheathing of tongued and grooved spruce, and lining of 18-oz. copper.

In all refrigerators having special concrete floors the lower edges of the insulating walls were covered with copper turned up on either side of the walls from 6 to 15 in., with the upper edges let into the wood. The floor of No. 1 was constructed as follows: The general floor construction of the room was brought to a level of approximately 1 in. of cement concrete thoroughly water-proofed, followed by 1-in. boards, cork-pitched, layer of water-proof paper with the joints well lapped and pitched, 1-in. board cork-pitched, layer of water-proof paper with the joints pitched, 1-in. board cork-pitched, and finished with approximately 3 in. of cement concrete properly graded to drains. The concrete was then covered with hexagonal vitrified white tile, properly laid, with a sanitary tile base around the outer walls of the compartment. In Nos. 17, 19, and 20 the concrete was covered with asphalt reinforced with armor plate. The floors of the other refrigerators were constructed in the same manner as the walls. On the copper bottoms specified for Nos. 3, 4, and 6, vitrified white tile was set in waterproof cement.

The doors have solid ash frames, double rabbeted, and insulated in the same manner as the walls, except the doors in No. 5 which are light slide covers, and the doors in Nos. 1, 19, 20, and 21, which are special Lorillard lap doors. The door sills in Nos. 1, 17, 19, and 20 are of heavy cast iron, tinned. The inner walls of the refrigerating pipe and coil lofts are protected against frost by the use of 18-oz. copper, tinned on one side. The floors of Nos. 3, 4, 5, and 6 are covered with 18-oz. copper, flashed to suitable height on the inner face of the walls. There are suitable tinned-copper drip-troughs under all refrigerating pipes, to collect moisture due to condensation and carry it to a drain in each refrigerator.

The storage compartments in Nos. 1 (except the vegetable compartment), 3, 4, and 6 are lined throughout with $\frac{5}{8}$-in. opal glass. The interior of No. 9 is lined with clear seasoned spruce, finished and shellacked. The interior of the vegetable compartment in No. 1, and Nos. 2, 5, 7, 8, and 10 to 21 are lined throughout with 18-oz. copper, tinned on one side.

The meat compartment in No. 1 has two sets of hook rails and supporting standards, with removable tinned meat-hooks, together with tiers of shelves constructed of pipe and angle iron heavily galvanized after fabrication. The shelves and shelf bearers in Nos. 3, 4, and 6 are of solid aluminum. There are wooden shelves for the storage of bottled goods in No. 9, and three tiers of shelves, of sheet metal heavily tinned, in No. 21.

Soda Fountain.—The soda fountain in the drug store was furnished and erected by the L. A. Becker Company, of Chicago, Ill. It consists of the fountain counter, with all necessary appurtenances, including a carbonating apparatus in the basement, and a back-bar or cooling compartment fitted to the circular wall of the room and over the window sill in front of which it is placed.

The fountain has a frontage of 9 ft. 8 in., is 4 ft. 8 in. deep, and 3 ft. 4 in. high. It is constructed of white Vermont marble with a 12-in. base and a 4-in. frieze of verde antique. All joints in the body are covered with white marble pilasters. The counter slab is $1\frac{1}{4}$ in. thick, and of such shape as to accommodate the syrup system. The refrigerator or cooling compartment is of white Vermont marble and has a 4-in. base and frieze of verde antique. The top slab is $1\frac{1}{4}$ in. thick, and is fitted over the granite window sill.

The two draft stands are of Becker's "Octagon" design, and are of selected and highly polished Mexican onyx. Each is fitted with one soda and two mineral water arms with brushed brass finish. The draft stands are provided with Becker's duplex circulating cooler system, which utilizes the carbonated water as a cooling agent and prevents the water in the leader pipes from becoming warm. Each draft arm leader pipe has an independent cut-off valve, allowing the operator to shut off the carbonated water supply from any draft arm at will.

All exposed interior work is faced with white Vermont marble trimmed with 16-oz. German silver. The basins have double reinforced concave bottoms, with undershot water inlets. There are eight 1-gal. syrup containers of vitrified sanitary porcelain, all fitted with Becker's dripless syrup pumps of Britannia metal heavily silver plated. All metals coming in contact with the syrups are 98% pure aluminum, non-corrosive, and immune from the action of fruit acids. There are also four ½-gal. crushed-fruit bowls and two compartments for ice cream.

The coolers furnished with this fountain are known as Becker's Reliable, and are of heavy seamless drawn copper with inner linings of pure block tin of sufficient weight to outlast the life of the apparatus. The refrigeration for the fountain and cooling compartment is supplied from the regular refrigeration system in the station, its source of supply being the refrigerating plant in the main power-house.

The cooling compartments are constructed of six layers of unlike materials, of different densities, for retarding and dissipating the heat. The walls are double, each composed of properly treated woods covered with layers of moisture-proof fiber board. The air space between them is filled with degummed flax fiber.

Lighting.—Although occupying the central portion of the station, the general waiting-room is supplied with abundance of natural light through semicircular windows in the north and south sides and the east end of the room, and through the glass roof over the ticket lobby at the west end. There are five windows on the north side and three on the south side, each 27½ ft. in diameter, and one in the east end 72½ ft. in diameter. The light admitted through the roof of the ticket lobby at the west end is equivalent to that received through a window 50 ft. wide and 60 ft. high. Considerable light also enters through the vestibules in the north and south sides of the room immediately

under the semicircular windows. On account of the unusual size of this room, particularly the height of the ceiling, a special lighting scheme was adopted.

In the design of this room provision was made for concealing the lamps and other equipment for artificial lighting. This was accomplished by providing ten alcoves along the north and south sides of the room immediately over the vestibules and in front of the 27½-ft. windows, and over the drug store and telephone-room, each 29½ ft. wide. In each alcove, behind a parapet, there is a bank of especially constructed, inverted, series, arc lamps, with corrugated-mirror reflectors about them to throw the light to the ceiling, whence it is reflected to the floor. The original scheme called for 18 lamps in each alcove, divided into three groups of 6 lamps each. Upon making experiments, looking to a uniform distribution of the light, it was found desirable to reduce the number in each alcove to 14, or two groups of 4 lamps each and one of 6, making a total of 70 lamps on each side, instead of 90, as originally intended.

In addition to the 140 lamps in the north and south alcoves, it was found necessary to place 8 lamps at the west end of the room and 14 at the east end, to produce an effect at night similar to that produced by natural light through the large window in the east end and the glass roof over the ticket lobby in the west end of the room. These lamps are above the colonnades, those at the west being at the north and south ends or above the bureau of information and stop-over ticket-office, while those at the east are distributed along the entire length. To soften and reduce the bluish-white glare of these arc lamps, light yellow-tinted cathedral glass screens are placed over them, and reflectors. Although this causes a loss of about 15% in their efficiency, the results are very gratifying.

This lighting equipment, consisting of 162 lamps, is connected so that several combinations can be had, throwing in by switches as many lamps as required. In addition to the arc lighting, there are 21 incandescent lamps in the ceiling of the east colonnade and 4 in the ceiling of the west; and floor outlets have been provided for the purpose of placing clusters of incandescent lamps on the backs of seats in the central portion of the room, should additional illumination be required.

Readings were taken with a luxometer for the purpose of getting

the results of the various combinations. The tests showed that the corrugated reflectors and light-colored ceiling produced almost perfect diffusion. With all lamps burning, readings taken about 4 ft. from the floor gave values of from 2.5 ft-candles in the corners to 2.3 ft-candles in the center of the room. The effect of this system of lighting is most pleasing when entering the station at night. No lighting equipment is visible, and very few shadows or light streaks are seen. The first impression is that the room is lighted by a slightly subdued natural light.

Natural light for the ticket lobby is provided by a glass roof over the entire space. The original scheme for artificial lighting contemplated the use of concealed lighting similar to that in the main waiting-room, but with smaller units placed in a groove or pocket in the side-walls of this room. With this system, however, it was evident that much light would be lost through the glass roof, as no glass could be found which would admit daylight freely, and at the same time prevent the escape of artificial light. After careful study and the necessary tests, it was decided to install Tungsten lamps above the glass ceiling. One 100-watt lamp is provided for each section into which the ceiling is divided, and each lamp has a metal reflector coated inside with aluminum paint. The lamps are arranged on four 3-wire circuits controlled by single-pole switches permitting cutting out one-half of the lamps without disturbing the symmetry of the lighted panels. The illumination in this room averages about 2.3 ft-candles, the quality of the light comparing favorably with that in the main waiting-room. The reflectors are of a special design, and are located so as to direct the light along radial lines, both the ceiling and glass roof of this room being curved. In this installation 225 lamps are used, and, on account of their construction, are suspended vertically.

The baggage checking-room on the north side of the ticket lobby is supplied with natural light by the saw-tooth roof construction, the north incline being glazed and the south being of book tile and composition roofing. In addition to the natural light thus admitted, considerable light enters through the windows in the north wall, facing the concourse. To insure the best results, each lamp has a large reflector, and the hollow tile work in the saw-tooth roof is painted with white cold-water paint. These precautions have resulted in destroying in a great measure color rings and shadows. The illumination in this

room averages about 1.8 ft-candles, and, for general illumination, is sufficient, but additional light is required at the desks, where records are kept and checking is done.

Outside of a small amount of concealed lighting in the state apartment, no effort was made to use this method in the other rooms of the station.

Owing to the location of the dining-room (being an interior room at the east end of the general waiting-room), no natural light could be secured from the sides, except through clerestory windows. To provide sufficient natural light, saw-tooth roof construction similar to that in the baggage checking-room was adopted, and to provide for the proper diffusion of the light thus admitted, an artistically coffered ceiling of metal and glass was provided. For artificial lighting, eight ornamental urns are suspended from the ceiling, in each of which are twelve 100-watt lamps on two circuits of six lamps each. Around the sides of the room, on the faces of the large piers, there are twelve ornamental bracket chandeliers, in each of which there are three 100-watt lamps. The alcoves in the north and south sides of the room are provided with ten ceiling fixtures, each containing three 100-watt lamps enclosed in hemispherical holophane globes. In addition to this lighting equipment, there are thirty-nine floor outlets, which will permit the use of electric lamps on the tables, in case additional illumination is necessary.

The lunch-room receives natural light from the clerestory windows and windows opening on the concourse. It is supplied with artificial light by six ornamental chandeliers suspended from the ceiling, in each of which there are twelve 100-watt lamps on two circuits of six lamps each, and six ceiling fixtures in the alcoves along the north side, each containing three 100-watt lamps enclosed in hemispherical holophane globes.

The women's waiting-room and toilet, and the men's smoking-room, barber shop, and toilet, face on the open portico extending across the front of the station, and, having large windows, are amply supplied with natural light. Artificial light in the women's waiting-room is furnished by three ornamental chandeliers suspended from the ceiling, in each of which are twelve 100-watt lamps on two circuits of six lamps each, and by nine wall brackets surmounted by holophane globes 14 in. in diameter, in each of which are four 50-watt lamps. The

smoking-room is artificially lighted by two ornamental chandeliers and ten wall brackets similar to those in the women's waiting-room. All the chandeliers and wall brackets are of solid bronze, finished in verde antique.

The state apartment faces the east portico, and is well supplied with natural light. Artificial light is supplied both by concealed and exposed methods. In the reception-room three handsome chandeliers are suspended from the ceiling, and each contains twelve 50-watt and six 100-watt lamps, and there are eight ornamental wall brackets surmounted by holophane globes, each containing four 50-watt lamps. The main entrance to the state apartment and the vestibules are lighted in a very satisfactory manner by concealed incandescent lamps with reflectors in the coves in the cornice at the springing line of the arches.

The open portico extending across the front of the building, the east portico, and the carriage porch are artificially lighted by ornamental bracket chandeliers on the interior faces of the piers forming the sides of the portico or colonnade, and by ceiling fixtures in the domes over the central pavilion, the domes south of the drug store and telephone booths, and the domes in the east portico and carriage porch. On the faces of the piers in the main entrance there are twenty bracket chandeliers, eight of which contain six 125-watt and one 187-watt lamps each; the remaining twelve contain three 100-watt lamps each. In the three domes over the main entrance there are ceiling fixtures, 5 ft. 8 in. in diameter, each containing six 100-watt lamps. The ceiling fixtures in the domes of the east portico and the domes south of the drug store and telephone booths are 3 ft. 6 in. in diameter, and contain six 100-watt lamps each. In the state entrance there are twelve bracket chandeliers, each containing three 100-watt lamps, and one dome fixture, 5 ft. 8 in. in diameter, containing six 100-watt lamps, while the carriage porch has thirty-six bracket chandeliers, each containing three 100-watt lamps. In the remainder of the south portico and in the east portico there are fifty-five bracket chandeliers, each containing three 100-watt lamps. All these fixtures are of massive bronze, finished in verde antique. The efficiency of the various fixtures was regulated by the requirements in the different sections of the portico.

The three vestibules in the south or main entrance to the general

waiting-room are lighted with fifty-four "sun-burst" fixtures attached to the granite ceiling panels. The five north or concourse vestibules are lighted by one hundred and twenty fixtures of the same design attached to the granite ceiling in the same manner. The drug store and telephone-room are lighted by ceiling fixtures consisting of 5½-in. holophane globes attached to the granite ceiling by brass collars finished in brushed brass. Ordinary 16-c.p. lamps are used in the above fixtures. The ticket cases and counters, the show cases in the drug store, the news-stand, and the flower booth are lighted by Frink reflectors, arranged so that the lamps are concealed as much as possible. Gem lamps are used in all cases where incandescent lamps are specified.

The fixtures for the offices and toilet-rooms are plain, three-light, brass, ceiling fixtures, painted black, the number in each office depending on the size and shape of the room. The lights are controlled by flush push-buttons on wood mats on the walls. The corridors are lighted by gem lamps encased in 8-, 10-, and 12-in. globes, according to their size.

The lighting of the concourse in the rear of the head-house required quite as much study as any other section of the station, if not more. The space covered by the roof is 130 ft. wide and 760 ft. long. The ceiling is an arch having a span of 130 ft. and a rise of 23 ft.; the height of the ceiling in the center is 45 ft. above the concourse floor. This space is used as a passageway between the train platforms and the head-house, and is lighted by seventy-two arc lamps suspended about 7 ft. below the ceiling. Before deciding on the scheme of lighting, many experiments were made. It seemed desirable to use concealed lighting, and, with this in view, series, direct-current, arc lamps were placed between the ceiling and the skylight roof construction. The scheme proved a signal failure, as the structural steelwork in the trusses cast very pronounced shadows, and the ceiling glass absorbed so large a percentage of the light given out by the lamps, that their location could hardly be determined from the concourse floor.

Flaming arcs were then tried, with much better results, on account of the great volume of light produced, but these lamps were abandoned owing to the difficulty and cost of maintaining them in the position in which they were placed. They also produced a very yellow light,

which was out of harmony with the general colors in the other parts of the building, although it is claimed that this defect could have been remedied. A serious objection to concealed lighting, however, was the tendency to flatten or nullify the ornamental plaster panels in the ceiling, particularly in the central section which is farthest from the floor.

Large diffusers, containing four or five units, were then tried, but were abandoned on account of objectionable shadows and streaks in the ceiling, due especially to the fact that the ceiling was not designed to accommodate lighting fixtures of that kind. The results would probably have been more satisfactory had the ceiling been designed to permit placing the diffusers in the ceiling instead of below it. The present system was adopted after the foregoing experiments had failed to produce satisfactory results. Each lamp is equipped with a clear inner globe and an opal outer globe, but, though the lighting is good, the glare or light spots produced by seventy-two arc lamps in one room is anything but pleasing when compared with concealed lighting.

The train signs and track numbers over the gates of the train fence are lighted by incandescent lamps, controlled by switches in cabinets containing the mechanism for operating the time signs of outgoing trains. The signs consist essentially of two square boxes or hoods, a small one for displaying the track number and a larger one for indicating the time of departure of trains. Beneath the latter there is a triangular hood with slots on two sides in which are placed slides containing the names of the principal stations reached by the given train. The small hood for displaying the track numbers is above the larger one. Three sides of the hood are of glass painted white on the back. The track number is painted on the face in black, using figures 3 in. high. At night this compartment is lighted with one 100-watt lamp.

The upper half of the lower hood contains a glass slide on which the word "Depart" is painted in black letters 3 in. high. In the rear of this space there are two 50-watt lamps. Below this slide there is a horizontal slot, $6\frac{1}{2}$ in. high and 15 in. long, behind which are three wheels having copper rims of sufficient width to permit the use of figures $5\frac{1}{4}$ in. high and $2\frac{1}{8}$ in. wide, for denoting the time of departure of trains. White canvas is glued over the openings in order to make them conspicuous in day time; at night the numbers are brought out

FIG. 1.—WASHINGTON TERMINAL STATION: GATE IN TRAIN FENCE, SHOWING TRAIN SIGN.

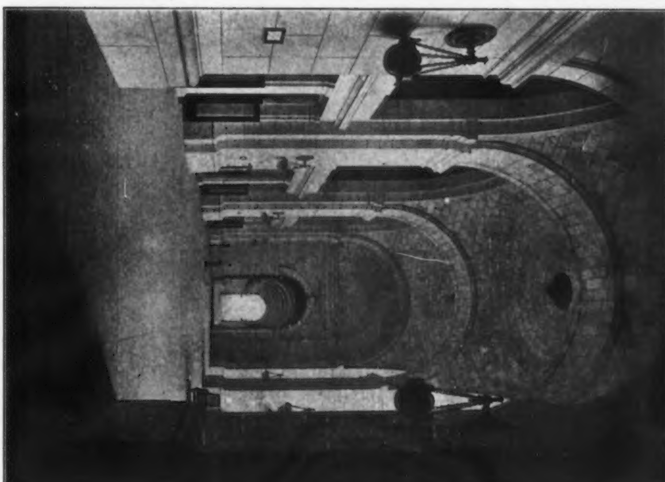


FIG. 2.—WASHINGTON TERMINAL STATION: PORTICO.

by the use of two 100-watt lamps. At the top, and in front of each of the slides indicating the points reached by any particular train, two 50-watt lamps with reflectors have been placed. In the bottom of each triangular hood over the gates there is one 100-watt lamp in a hemispherical holophane globe.

The lighting for the signs and the use of the gateman at each gate is equal to 700 watts, or a total of 22 400 watts for the thirty-two gates. The total lighting equipment on the train fence is equivalent to about five hundred and sixty 16-c.p. lamps.

The train platforms and umbrella sheds are lighted by 187-watt gem lamps placed at intervals of 30 ft., or midway between the supporting columns along the entire length of each shed. The lamps are suspended from the lower side of the central beam forming the roof construction, and each is equipped with a prismatic bowl reflector. The results are very satisfactory.

The power wires furnishing current for the lighting are carried, between the power-plant and station and express building, through vitrified tile ducts in the pipe tunnels in the west retaining wall and under the north sidewalk of H Street. The pipes for elevator, water, and fire service, heating, refrigeration, etc., are carried on supports suspended from I-beams embedded in the concrete roofs of the tunnels, and the vitrified ducts are built in stacks along the walls, with manholes at convenient intervals. There are forty-eight lines of 2-in. ducts between the power-house and the station, and six lines to the express building. All wiring in the buildings is encased in electro-galvanized iron pipe furnished by the Safety Armorite Conduit Company, the smallest size being ¾-in. All short bends were made at the factory and galvanized after the bending had been done. The long bends were made in the field, but, in bending, the use of heat was not permitted.

The high-tension distribution system for incandescent lamps and motors is operated at 2 300 volts and 60 cycles. The transformers for lighting purposes and sets of transformers for motor circuits are served by independent cables direct from the switch-board at the power-house. The arc service cables are of four or eight conductors, and serve two or four loops. All motor-driven apparatus is operated from 3-phase lines, and all incandescent service is taken from one phase of the generator.

The cables conveying current north to the coach yards, shops, and signal towers are lead-covered on account of dampness in the ducts; those south to the station are double-braided, the ducts being reasonably dry. The 2 300-volt cables are insulated with varnished cambric over a thin layer of unvulcanized rubber, and were subjected to a test of 7 500 volts for 5 min. between conductors and ground, after being submerged in water for 24 hours at the factory, and 5 000 volts for 5 min. after being installed. Each conductor in the arc cables is insulated with rubber, with varnished cambric over all, and was required to stand a test of 10 000 volts at the factory and 8 000 volts after installation, under the conditions mentioned above. All high-tension cables were supplied by the General Electric Company.

The necessary transformers, with a ratio of 10 to 1, are housed in brick and concrete vaults at convenient points in the basements of the various buildings, the area covered by the vaults in each case being sufficient to permit changing or making repairs without disturbing the transformers in service. Each vault has asbestos-lined doors, and the necessary locks and keys. The doors are of such size as to permit the convenient handling of apparatus in or out of the vault.

The high-tension cables leading to each transformer terminate in a set of disconnecting switches attached to the wall above the transformer, and there are expulsion plugs between the switches and the transformer. The distributing panels for the low-tension feeders are encased in iron cabinets attached to the outside walls of the vaults on either side of the doors. Connection between the transformers and cabinets is made through iron pipe conduits. From these cabinets three-wire, 113-226-volt feeders are carried to the distributing cabinets located at convenient points in the building, each feeder serving from one to six distributing cabinets.

The distributing panels are encased in sheet-iron cabinets and equipped with three-wire buses and two-wire branches, all controlled by knife-switches, the branch circuits being protected by plug-fuses and buses, and the feeders by type "A" fuses. No switches smaller than 25-ampere rating have been used on branch circuits, or smaller than 150-ampere rating on main circuits.

All insulating joints were entirely eliminated. The neutral wire of the branch circuits is grounded to the conduit system at the fixture outlet and at the cabinet, at the latter by a copper wire connecting the

conduit system with each neutral wire. The neutral wire in the feeder circuits is grounded to the conduit system at the cabinets and at the transformers by ground-plates embedded in charcoal under the vault floors.

All secondary wires are insulated by Okonite compound, in accordance with the U. S. Navy Yard and Docks Specifications for low-tension wires. Feeders and tie lines are single-conductor; branch circuits are twin-conductor. Insulation resistance tests gave results from three to twenty times greater than called for by the District of Columbia regulations.

The wiring system for the whole lighting installation, together with a system of conduits for telephone, telegraph, telautograph, and annunciator wires, was put in by A. S. Schulman, of Cincinnati, Ohio, in accordance with working drawings and specifications prepared in the office of the General Superintendent of Motive Power of the Pennsylvania Railroad Company.

Lighting Fixtures.—All lighting fixtures in the station building, except those used in connection with concealed lighting and a few used with Frink reflectors, were furnished and erected by the Sterling Bronze Company, of New York. All special fixtures were furnished complete, including wiring, sockets, globes, shades, and holders, ready to receive the lamps. The office fixtures were furnished complete, except the shades, which were purchased by the Terminal Company direct.

All fixtures, with the exception of those in the offices, are of cast brass, from special designs prepared by the architects. The designs and styles of finish were varied to suit the treatment in the various portions of the structure. The sizes were arranged as far as possible to permit the use of standard shades and globes. The fixtures in the offices and toilets are of the ordinary designs used for such purposes, finished in black oxide.

The horizontal diameter of each of the three fixtures in the state reception room is 3 ft. 6 in. over all; the neat diameter is 2 ft. 6 in. The center of the chandelier is about 16 ft. above the floor and about 12 ft. 8 in. below the ceiling, and is suspended by a heavy brass chain. The small globes around the outside are of holophane glass, and the panels in the large globe are of roughed inside glass, leaded in design.

The three ceiling fixtures in the domes over the central pavilion, and

the one in the dome over the state entrance, are 5 ft. 8 in. in diameter, with glass bowls 3 ft. in diameter. To prevent the glass in these bowls from falling in case of breakage, silver wire netting has been placed around them. Five fixtures of this design, 3 ft. 6 in. in diameter, were placed in the domes of the east portico, two in the domes of the south portico opposite the drug store and telephone room, one in the barrel vault between the carriage porch and the ticket lobby, and one in the ceiling of the vestibule between the general waiting-room and the lunch-room. The globes in these lamps are 2 ft. in diameter and are of holophane glass.

The 32 fixtures on the soffits of the train sign hoods over the gates in the train fence are 13 in. in diameter, and have 8-in. holophane bowls.

Side fixtures are attached to the faces of the masonry piers, 12 in the state entrance, 36 in the carriage porch, and 20 in the main portico. The lower globes are of holophane glass, and are 16 in. in diameter; the upper globes are of clear glass, and much smaller. The canopies are 28 in. in diameter, and are secured to the stonework by expansion bolts. There are 55 fixtures of the same design in the south and east porticos, the lower globes in which are 14 in. in diameter, and of holophane glass; the upper globes are of clear glass. The canopies are 22 in. in diameter. There are 12 fixtures of the same design and construction in the dining-room, the dimensions being the same as those in the south and east porticos, except the canopies, which are 28 in. in diameter.

There are 2 hanging lamps in the smoking-room, 3 in the women's waiting-room, 6 in the lunch-room and 8 in the dining-room. The body of each fixture is about 4 ft. in diameter, and is about 10 ft. below the ceiling. The bottom globe is of roughed inside glass in four panels; the glass bowl is 30 in. in diameter, and the upper globe of clear glass.

There are 8 wall brackets in the state reception room, 9 in the women's waiting-room, and 10 in the smoking-room, in which the holophane globes are 14 in. in diameter and the canopies 22 in.

The granite ceiling panels of the south vestibules have 54 fixtures, the north or concourse vestibules 120, the east colonnade 21, and the west 4.

Each of the 41 fixtures attached to the gate posts of the train fence on the concourse, for use in connection with the train starting signal system, has two opalescent globes.

The alcoves of the dining- and lunch-rooms and the office entrances have ceiling fixtures 23 in. in diameter, with 16-in. holophane globes. Fixtures of the same design, 13½ in. in diameter, with 10-in. bowls, were placed in the elevator cabs and passages around the state apartment, 3 in the former and 6 in the latter.

In the corridors of the station there are 135 ceiling fixtures, the globes ranging from 8 to 12 in. in diameter, depending on the size of the lamps used. All the globes on the corridor lamps are of opalescent glass.

In the drug store and telephone-room there are 46 fixtures having holophane globes, 5½ in. in diameter.

The fixtures in the state apartment are finished in rich gilt. Those in the drug store, telephone-room, vestibules, and colonnades are antique brushed brass. Those in the lunch-room, dining-room, women's waiting-room, smoking-room, and all porticos and pavilions, are finished in verde antique, Tiffany color. Those on the train fence, office entrances, elevator cab, and corridors are all finished in black oxide.

Train Yard.

The train yard, immediately north of the concourse, is 760 ft. wide, or equal to the length of the concourse. One-half of the yard is on either side of the center line of Delaware Avenue, which is taken as the longitudinal axis of the depot and train-yard site. The tracks in this space are divided into two groups, one section, 480 ft. wide, containing the stub or high-level tracks, the other section, 280 ft. wide, the through or low-level tracks, leading to the First Street Tunnel.

There are twenty high-level tracks laid singly and in pairs, as shown by Plate II, and thirteen platforms in the spaces between the tracks, three exclusively for handling baggage, the other ten for both passengers and baggage. On the low-level section, provision has been made for thirteen tracks, nine of which connect with the tunnel tracks, the other four being stub. At present, only eleven tracks are laid, the remaining space being used temporarily for handling mail. This section has five platforms, each 20 ft. wide, for both passengers and baggage.

The platforms for the joint use of passengers and baggage on the high level are 20 ft. wide, and the baggage platforms are 17 ft. At the station end of the latter, there are baggage lifts for handling baggage between the basement baggage-room and the train platforms. The

south or station end of each platform on the low level terminates in an elevator used for moving baggage between the platforms and the sub-basement.

In operating the high-level yard, the trains carrying heavy baggage use, as far as possible, the tracks adjacent to the baggage platforms. In this way there is comparatively little interference between passengers and baggage trucks. As no baggage platforms were provided on the low level, on account of lack of space, there is more interference. To facilitate the handling of baggage, having in mind especially the great area to be covered and the long distances to be traversed, there are twelve ½-h.p. electric baggage trucks, constructed at the Altoona shops of the Pennsylvania Railroad Company. The speed and power of these trucks have effected a marked saving in the handling of baggage.

The high-level tracks descend northward on a grade of 0.55% from the station to a point near K Street. The low-level tracks ascend on a grade of 0.8% to the same point. From this point north all tracks ascend northward on a grade of 0.95% to Florida Avenue. At this point the rates of grade on the various tracks change; the Metropolitan Branch to 0.7%; the coach yard to 0.5%; while the Washington Branch of the Baltimore and Ohio and the Philadelphia, Baltimore, and Washington Railroad continue to ascend at 0.95% to 12th Street tower where a summit is reached.

Umbrella Sheds.—The tracks in the train yard are not covered by one large shed, or by a series of large sheds, but each platform has its individual shelter, known as an umbrella shed. Among the reasons leading to the selection of this kind of shelter are the comparatively mild climate and the absence of heavy snows, the cost of erection and maintenance, their desirability on account of cleanliness and light, and because the height of a large shed or series of large sheds would have dwarfed the station and all other buildings in the vicinity.

The umbrella sheds are supported on Ionic columns of cast iron, about 16 in. in diameter at the base, and located at intervals of 30 ft. Each shed on the high level is composed of 23 bays, or 690 ft. in length, which, with the overhang along the north wall of the concourse, gives a shelter for each platform 705 ft. long. The north end of the low-level sheds is opposite those of the high level, but the south end is shortened by the stairways leading from the concourse to the low-level tracks. The roof construction of the shelters is economite

PLAN OF WASHINGTON TERMINAL STATION.

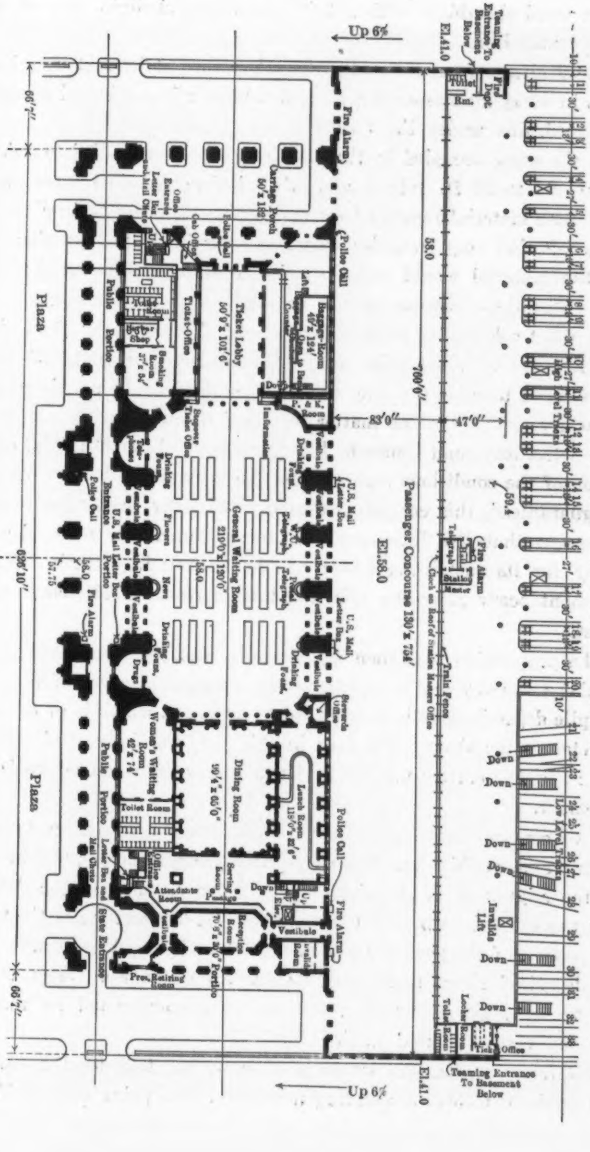


FIG. 2.

tile on wood sheathing, with a 5-ft. continuous skylight on each side of the center line.

The drainage from these sheds is taken care of by cast-iron downspouts in every alternate column, from which it is conducted to sewers by cross-drains under the tracks.

As the space occupied by the high-level tracks was filled to a depth of from 25 to 35 ft. only a short time before the shed construction began, with material ranging from sand to lumps 3 or 4 ft. in diameter, it was felt that very irregular settlement was likely to take place and that the material would not reach its limit of settlement for some years. For these reasons special foundations were necessary.

As the track grades in this section ranged from 54 to 58 ft. above tide, the use of wood piles was not considered prudent. Concrete piles seemed to offer the only solution, as they would not deteriorate in the dry loose fill. The matter was then discussed with representatives of the Raymond Concrete Pile Company. After a careful examination of the conditions under which the work would have to be done and guaranteed, this company refused to consider the proposition for the reason that the Raymond pile, being conical in form, depends largely for its sustaining power on the surrounding earth. Should settlement occur after the pile had been driven, its efficiency would be lost.

The proposition was then submitted to the representatives of the Simplex Company and accepted, as the sustaining power of the Simplex pile depends more largely on the blunt point, which is of the same diameter as the shaft. The load in this case was light, and any settlement of the earth could do no harm unless there should be lateral movement.

Two concrete piles, each about 40 ft. long, were driven for each column, and, at this date, two years after the station was put in service, the alignment of the sheds seems to be as good as the day the work was erected. Piles were not used on the low section, as the fill on this portion of the yard did not exceed 10 ft. in depth, and most of it was deposited about three years before the sheds were erected. On this account, also, concrete platforms were constructed on the low level, but wood was used on the high.

Retaining Walls.—As stated previously, the high-level tracks are on a grade of 0.55%, descending northward to a point near K Street,

FIG. 1.—WASHINGTON TERMINAL STATION: UMBRELLA SHEDS.

FIG. 2.—SOUTHERN PORTION OF EXPRESS BUILDING, SHOWING TRAVELER USED IN ERECTION OF STEELWORK.

while the low-level tracks are on an ascending grade of 0.8% to the same point. This caused a difference of elevation of 20 ft. at the concourse, and required the high- and low-level tracks to be separated by a masonry retaining wall, extending northward from the concourse to a point near I Street, where the grades practically reach the same elevation.

The entire terminal site, extending from the north line of the concourse to L Street, is enclosed by masonry retaining walls, with cross-walls defining the streets crossed by the terminal construction. There is also a retaining wall in Delaware Avenue between L and M Streets, as required by Act of Congress, for the purpose of preserving the east 40 ft. of this avenue as a public highway. All these walls have a stone facing and Portland cement concrete backing, mixed in the proportions of 1 part cement, 3 parts sand, and 5 parts broken limestone. All ashlar is of Mahoning sandstone, obtained from quarries in West Virginia and Western Pennsylvania; the stone for the concrete was from the limestone quarries of West Virginia.

Both guy and stiff-leg derricks, as best suited the conditions, were used in handling the material for the walls. Where the structure was short enough to be covered by one outfit, the guy derrick was generally used. For the long walls, stiff-legs were generally used, in most cases on runways permitting prompt movement along the line of the work. Conditions beyond the control of the company, however, in many cases interfered with the logical prosecution of the work, consequently, most of the long walls were built piecemeal.

Pipe Tunnels.—There is a tunnel, 12 ft. wide and 13 ft. high, in the base of the west retaining wall, between the station and the power-house, for the purpose of taking care of light and power wires, and pipes carrying steam, air, water, and hydraulic pressure between the power-plant and the station. At H Street it was necessary to depress the tunnel so as to pass under the street; and, on account of the underground trolley tracks, its height had to be reduced to 8 ft.

A branch tunnel, 5 ft. wide and 7 ft. high, was constructed under the north sidewalk of H Street, in which to place the wires and pipes leading to the express building. This tunnel was constructed as a part of the foundation of the north abutment of the H Street Bridge. The wires are cared for in terra cotta conduits built against the sides of the tunnel; the pipes are supported on beams built in the roofs. In the large

tunnel I-beams were built in the soffit of the arch at intervals of 10 ft., the lower flanges projecting a sufficient distance below the soffit to permit clamping the pipe racks to them. T-rails were used in the roof of the small tunnel in lieu of I-beams.

Concrete Mixers.—As large quantities of concrete were required in the construction of the north approach to the Union Station, rather elaborate plants were put in for mixing it. The first masonry built was in the train-shed section, hence the first mixing plant was erected on that section.

At a point near the intersection of G Street and the east terminal line a 5-ft. cubical mixer was placed, at a height of about 8 ft. above the ground. About 100 ft. distant a pit 16 ft. wide, 40 ft. long, and 11 ft. deep was provided. Two standard-gauge tracks were laid across this pit and for a distance of several hundred feet beyond. One track was used for handling and storing stone, the other for sand.

A cement house having a capacity of 2 500 bbl. was built near the pit. A narrow-gauge track, extending from the bottom of the pit to a point above the mixer, delivered sand, stone, and cement to the latter. The crushed stone and sand were delivered on the ground in steel hopper cars. The storage tracks were laid on a grade sufficient to permit the movement of cars by gravity.

The operation of this plant was as follows: The stone and sand cars being placed over the pit, the material was dumped from the cars into hoppers beneath the tracks. A specially designed car, holding, when full, sufficient material for one batch of concrete, was placed first under the stone hopper and the requisite quantity of stone allowed to run in. The car was then moved to the sand hopper, from which the necessary sand was obtained. The cement was then added. The proper proportions of ingredients were determined by metal strips placed on the sides of the car from actual measurements.

After receiving the proper quantities of sand, stone, and cement, the car was drawn up the incline by a cable to a point over a hopper above the mixer, and there dumped automatically and allowed to return to the pit. The material was then dropped from the hopper into the mixer. The necessary water was added by an automatic device which could be regulated according to the condition of the sand and stone.

The power for operating the mixer and for hauling the material

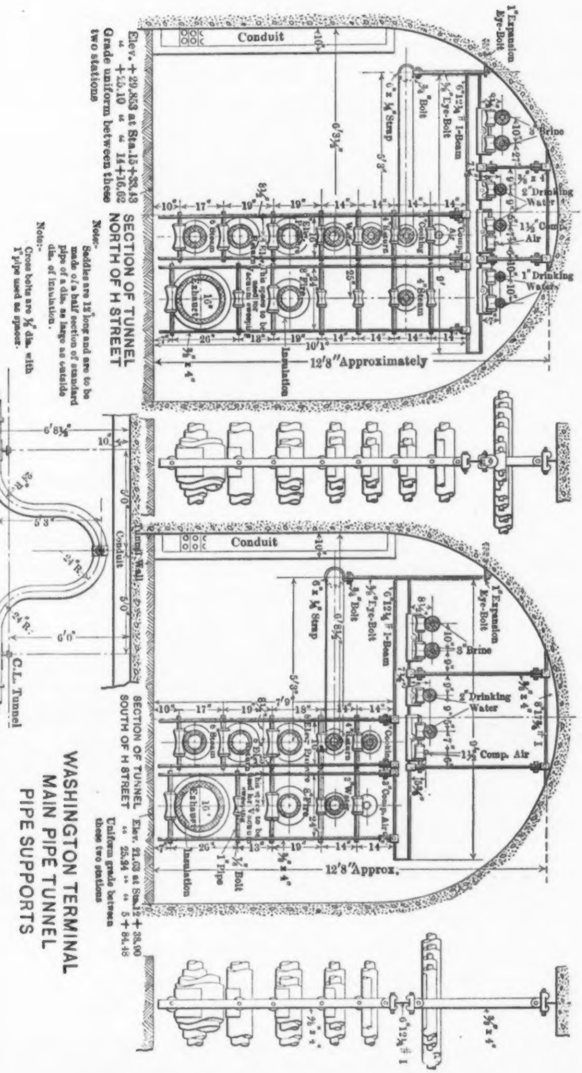


FIG. 8.

WASHINGTON TERMINAL
MAIN PIPE TUNNEL
PIPE SUPPORTS

up the incline was furnished by the same boiler. When the batch was properly mixed it was dumped into a bucket on a truck car, and conveyed by horses to the point where it was to be used. The actual time required to mix a batch after the material had been placed in

PIPING IN H STREET PIPE TUNNEL

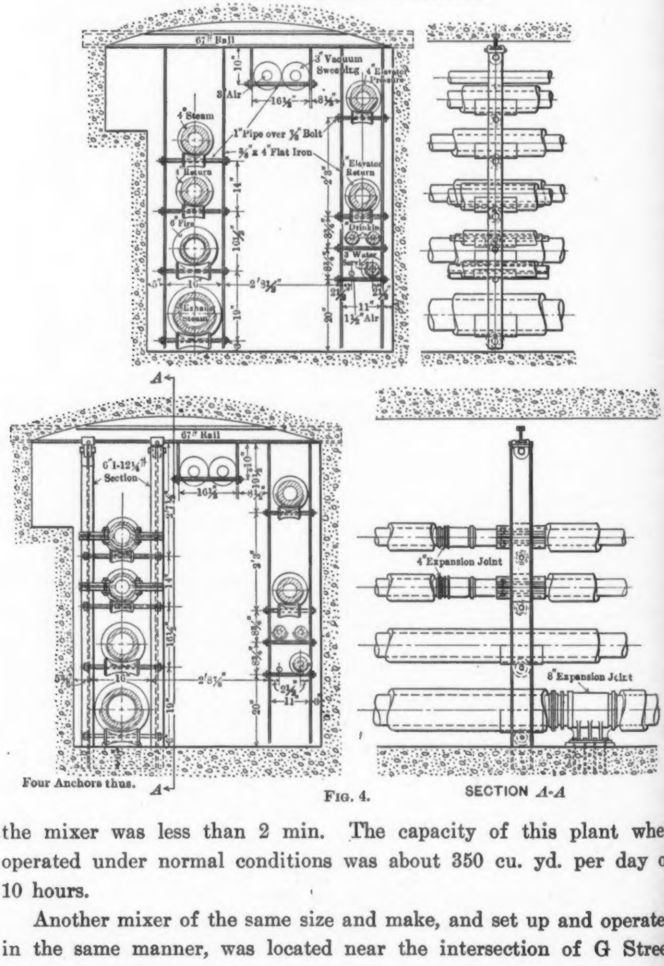


FIG. 4. SECTION A-A

the mixer was less than 2 min. The capacity of this plant when operated under normal conditions was about 350 cu. yd. per day of 10 hours.

Another mixer of the same size and make, and set up and operated in the same manner, was located near the intersection of G Street

and the west terminal wall, but, instead of a pit, as in the foregoing plant, there was a double-track trestle 220 ft. long, under which bins for stone and sand were provided. Beneath it, and extending its entire length, were two subways, each 6 ft. square, in which narrow-gauge tracks were laid for handling material. One line of bins was used for stone, the other for sand.

Near the trestle a cement house was constructed in such a manner as to permit the delivery of bags of cement to it by a chute. The cars for delivering material to the mixer were divided into two compartments, for sand and stone, respectively. In operating this plant, the cars were first passed under the sand-bins, from which the requisite quantity of sand was delivered to the sand compartment through apertures placed at regular intervals in the bottom of the bins. The cars were then pushed by hand to the extreme end of the subway and upon a transfer table, by which they were moved laterally to the line of track under the stone-bins. The necessary stone was then delivered to the second compartment. The cars were then moved to the outer end of the subway where there was a hopper for the delivery of cement. This hopper was constructed so as to hold the proper quantity of cement for a batch of concrete of given proportions. To facilitate the handling of cars under the material bins, the tracks were laid on a slight descending grade in the direction in which the cars were to be moved; in other words, there was a descending grade between the mixer and the transfer table, and a similar grade between the transfer table and the foot of the incline. The tracks on the incline between the material bins and the mixer were connected at the top of the incline by an automatic switch. Thus the empties were returned to the bins by one track and the loads were taken to the mixer by the other.

The capacity of such a plant depends on the speed at which the finished material can be removed. The output under normal conditions was about 400 cu. yd. per day of 10 hours. This plant had an advantage over the first one because the bins provided a place for the storage of material and permitted the prompt unloading and releasing of cars, which could not be done with the other plant, particularly when delays, on account of bad weather or for other reasons, prevented the operation of the mixer.

A Hains mixer was installed later at L Street for mixing the

concrete for the abutments and retaining walls in that vicinity. The stone and sand were dumped into buckets from cars on temporary tracks over the streets and hoisted to the material platform at the top of the mixer by derricks. The quantity of masonry in this locality was too small to warrant the construction of an incline for the handling of raw materials. The capacity of this mixer depended entirely on the speed with which the material could be delivered to and taken from the plant. Under proper working conditions, with the materials located for expeditious handling, it had a capacity of about 400 cu. yd. per day.

Mixing plants similar to the one first described were erected at T Street and New York Avenue Bridges for mixing the concrete in these structures. Hains mixers were used for mixing the concrete for the station-building foundations, and for the masonry at the north end of the First Street Tunnel immediately in front of it.

Sub-surface Obstructions.—Considering the magnitude of the work and the radical changes in conditions, there were comparatively few sub-surface obstructions. Those of the greatest importance were a 9½-ft. trunk sewer in the bed of F Street, which formed part of the station site, and a 15 by 17½-ft. trunk sewer on the south side of Florida Avenue. To divert the F Street sewer required the construction of about 1 400 lin. ft. of new sewer across the plaza, at an expenditure of about $42 000.

Had Florida Avenue been depressed in accordance with the original plan, it would have exposed the top of the large sewer above mentioned. To avoid disturbing it, a slight increase in the rate of grade was made between K Street and Florida Avenue, and a reduction of about 6 in. in the depth of the bridge construction over this avenue. This plan left sufficient covering to permit the use of standard sidewalk construction. On account, however, of the proximity of the foundations of the south abutment on one side and the south line of pedestals on the other, it was necessary to reinforce the sides with concrete.

Other obstructions of minor importance, but causing considerable expense, were the 24-in. water main on K Street, which had to be depressed for a length of more than 1 100 ft., the greatest depth of trench being 15 ft. below the original street surface; the 24-in. gas main on Massachusetts Avenue, which had to be relocated for a distance of 4 200 ft., and the 12-in. main on G Street a distance of

2 500 ft. Similar but smaller obstructions were met on all streets and avenues where the grades were materially changed, and were either lowered or reconstructed.

Surface Obstructions.—On February 28th, 1903, when the Union Station Act was passed, the entire terminal area between Massachusetts Avenue and L Street was occupied by solid blocks of residences, stores, warehouses, and the main tracks of the Baltimore and Ohio Railroad; and to the south of the terminal area, on property to be utilized in part in forming the plaza and its approaches, were the main passenger and freight tracks, yards, and stations of the Baltimore and Ohio Railroad, together with some private property occupied as business places and residences.

Before the railroad property required in the building of the new station could be vacated, new coal and freight yards had to be constructed. Work was started on June 1st, 1903, 3 months after the passage of the Act, or as soon as plans could be prepared and property secured, and the old facilities were completely abandoned in August, 1904, 15 months after the work was started and about 9 months after work on the station was begun.

During this time the foundations for the east end of the station, involving about 20 000 cu. yd. of concrete and large quantities of excavation, were completed, and some preliminary work was done on the west end. The available space, however, was such that active work on the masonry at this point could not be started before the coal yards were completely abandoned. In October, 1904, the passenger traffic was thrown to the west side of the approach, thus removing the last obstruction to the progress of the work on the station building.

Foundations.

The most serious problem to be dealt with on this work was foundations. Generally speaking, the foundation conditions were bad on nearly every part of the work, excepting portions of the coach and engine yard, and, with this exception, safe foundations were only secured after going to unusual depths. Material capable of sustaining the weight of the Y-bridge and the coach yard and shop buildings was found at a depth of 3 or 4 ft. below sub-grade, and consisted of sand in the coach yard and dark red clay in the shop yard.

On the station site a bed of gravel was found at an elevation of

about 10 ft. above tide, or from 12 to 15 ft. below the existing surface of the ground. The material excavated indicated that this locality was at one time a ravine and that a small stream flowed through near the north limit of the station site. Black loam, giving evidence of being decayed vegetable matter, was found immediately above the gravel bed. The 10 or 12 ft. of material overlying the original soil of the ravine was "made ground," and consisted of a fair quality of clay, but of poor sustaining power.

At H Street, about 800 ft. north of the station, no gravel was found, except a small quantity mixed with the clay, though at the west end of the bridge the excavations were carried approximately to tide, or a depth of about 25 ft. below the street surface. The material at this elevation was fine sand with a small quantity of blue clay of very unstable character. Although enormous quantities of water were encountered in putting down these excavations, an abutment having a total height of about 53 ft., built on this material, has never shown any signs of settlement.

The foundation conditions at the power-house stack and the method adopted to provide adequate support for it are described later. Clay containing sufficient gravel, however, to support the walls and pedestals of the power-house was found at an elevation of 22.5 ft. above tide. The material either above or below this elevation did not show a safe bearing capacity. As no indications of settlement have appeared up to the present time, it is presumed that the foundations are adequate.

The worst conditions on the entire work were met at K Street, where the original ground was about 48 ft. above tide. Tests showed nothing substantial at an elevation of 10 ft. below tide or 58 ft. below the surface. A careful examination of the material in this locality showed about 28 ft. of yellow clay containing thin layers of gravel, not sufficient, however, to provide suitable foundations for heavy construction. Beneath this, to a depth of about 15 ft., there was blue clay of about the consistency of putty. Under this, to an uncertain depth, was found a sandy material, containing sufficient clay to endanger its stability. Test piles were then driven, but failed to locate material showing proper sustaining qualities until a depth of 25 ft. below tide was reached, nearly 75 ft. below the original surface. When assured of these conditions by the above tests, it was decided to put in pile foundations for approximately the west half

of both abutments. At L Street some blue clay was encountered, but not enough to require the use of piles.

At M Street and Florida Avenue, where the street surfaces were lowered 15 or 16 ft., a fair quality of sand was encountered, so that the foundation conditions at these points might be considered normal. A ravine, about 20 ft. in depth below the established grade, ran across what is now the west end of the New York Avenue Bridge. Several years before the terminal improvements were started, this ravine was converted into a city dump and filled to grade with miscellaneous material, largely rubbish and ashes.

To secure suitable material to support the bridge, it was necessary to go to a depth of from 25 to 36 ft. The latter depth was reached at the east abutment, which is built over a trunk sewer, the top of which is about 25 ft. below the surface of the ground. To protect the sewer, an arch was formed in the abutment, the masonry on either side being carried down to a point at or below the bottom of the cradle. The west abutment and the intermediate piers were carried to a depth of about 25 ft. below the roadbed, at which elevation sand of fair bearing capacity was found.

At T Street Bridge reasonably good foundation conditions prevailed, except at the west end, where the same ravine was found and where the same sewer was in the way of a pier. Foundations of normal depth were found at the sites of all the buildings in the engine and coach yards, including the pivot piers of the turn-tables at the shops. The only troublesome foundations in this vicinity were those of the locomotive inspection pits, which fell in a swampy ravine requiring an additional depth of about 10 ft. of excavation and masonry.

Bridges.

Within the city limits all streets and avenues north of the station were depressed so as to permit them to be taken under the railroad tracks. As the grade established for the tracks from K Street northward coincided very closely with the original surface of the ground, it was necessary to lower K, L, and M Streets and Florida Avenue a maximum of from 12 to 16 ft. at their points of greatest depression. The grade of the low-level tracks required the depression of H Street a maximum of about 11 ft. These depressions were carried a distance of from 300 to 500 ft. beyond the terminal lines, in order to avoid

excessive grades. Second Street, E., was lowered to conform to the new grades of intersecting streets from G Street to its intersection with Delaware Avenue near L Street, and from N Street to Florida Avenue. The east 40 ft. of Delaware Avenue, between L and M Streets, was also depressed to coincide with the new elevations of those streets.

In order to reduce to a minimum the depression of the various streets and avenues, it was decided to adopt a shallow floor system. This could only be obtained by the use of short spans. A width of 80 ft. at right angles to the axis of the street was adopted for all streets and avenues to be bridged. As a double-track street-car line occupied H Street, and one was in prospect at Florida Avenue, the Commissioners agreed to permit the use of three-span structures in all cases. The center bay spanning the street-car tracks was made 25 ft. in length, from center to center of columns, and the side-bays, 27 ft. 6 in. between the centers of the columns and the faces of the abutments. The center spans and inner ends of the side-spans were supported on columns and box girders, the outer ends of the side-spans on abutment walls defining the new street limits. As a water-tight structure was desired, and the track arrangement precluded the use of anything but deck construction, I-beams encased in concrete were used.

In all bridges, except over Florida Avenue, 24-in., 80-lb., I-beams, spaced at intervals of about 18 in., were used. These beams were embedded in concrete, the bottom of which extended 2 in. below the bottom flanges, the top being flush with the tops of the beams. Upon the surface thus formed a $\frac{3}{4}$-in. layer of a Texas oil residuum, known commercially as Hydrolene B, was used, the top of which was covered with heavy burlap. As a protection to the water-proofing, a layer of reinforced concrete, from 5 to 6 in. thick, was used. The track superstructure consisted of 6 in. of ballast, 7-in. ties, and $5\frac{3}{16}$-in. rails, the entire depth of construction from top of rail to bridge seat being 4 ft. The construction of the Florida Avenue Bridge was similar, but the I-beams were 20-in., 80-lb., and spaced at intervals of about 12 in. from center to center.

The bridges at Florida Avenue and M Street each carry ten tracks, and are about 135 ft. wide, divided into two sections accommodating five tracks each. There is a space in the center, 4 ft. wide, for pris-

matic lights for lighting the subways beneath. The L Street Bridge is about 220 ft. wide, and carries, in addition to the ten tracks, switching leads for the east and west sides of the train yard. This bridge has in the center an opening, about 10 ft. wide, covered with Clinton wire cloth, for lighting and ventilating the subway. The bridge at K Street is about 450 ft. wide, and has a 10-ft. opening approximately in the center, with two spaces, about 3 ft. wide, containing prismatic lights on either side.

The construction of H Street Bridge was more complicated. The platforms of the train yard extended across this structure and necessitated a style of construction which would raise the tops of the platforms 8 in. above the top of rails of the adjacent tracks. This structure is about 790 ft. wide, and contains 18 platforms, one-half of which are of prismatic light construction, the other of reinforced concrete. It is divided into two sections, one about 496 ft. long, carrying the high-level tracks, the other nearly 300 ft. long, carrying the low-level tracks. The difference in elevation between the high- and low-level sections at this point is about 8 ft. There is a vertical opening for ventilation between the bottom flange of the fascia girder of the high-level section and the top flange of the fascia girder of the low-level section. This opening is protected by Clinton wire cloth.

In addition to the bridges for carrying the tracks over the various streets and avenues, two bridges were erected for carrying streets and avenues over the railroad tracks. One is a steel truss bridge consisting of four spans, aggregating 712 ft. in length, with asphalt roadway and concrete sidewalks, erected on the south half of T Street for carrying the street traffic over the Baltimore and Ohio Railroad freight storage yard, the Metropolitan Branch tracks, the north end of the coach yard, and the Y-tracks between the Metropolitan and Washington Branches. The other is a steel plate-girder and I-beam bridge, encased in concrete, on the line of New York Avenue, spanning the main tracks of the Washington and Metropolitan Branches of the Baltimore and Ohio Railroad, the Magruder Branch of the Philadelphia, Baltimore and Washington Railroad and the south end of the coach yard; its total length on its center line is about 410 ft.

Water-proofing.—In order to keep the various subways as dry as practicable, the backs of all abutments, as well as other portions of the terminal construction, were water-proofed with the material used in

water-proofing the decks of the bridges. This material, up to the present time, seems to show satisfactory results, where used for level surfaces when properly protected. Its use for vertical walls, however, cannot be recommended, as it does not possess the adhesive qualities necessary for this purpose. It was also found that, on exposure to the hot summer sun, it had a tendency to separate at the offsets and drop down. It is also believed, from present appearances, that the settlement of the fill back of the abutments has in some instances torn the water-proofing loose, leaving the walls exposed.

On account of the failure of Hydrolene as a water-proofing substance on the backs of the abutments of bridges on the terminal, coal-tar was substituted for these parts of the New York Avenue and T Street Bridges. It was applied with a mop, two or three applications being given; at the present time it is giving very satisfactory results.

Outside of these cases, the only other water-proofing north of the station was in the pipe tunnel under the north sidewalk of H Street, leading to the express building. Soon after this work was completed, water began entering this tunnel through the south wall, and, as the bottom of the tunnel at the west end was 3 or 4 ft. below the normal ground-water line, a contract was made with the E. J. Winslow Company, of Chicago, to apply Winslow's hydrolithic compound. After this material had been applied, to the proper height, the water seemed to rise, entering the tunnel above the normal line. An investigation disclosed a broken water pipe in the street near the south wall of the tunnel. After the pipe was repaired the tunnel became practically dry, indicating that the greater part of the trouble was due to that source. In order to take care of any water which might find its way into this subway in the future, a sump was constructed at the lowest point, where a small electric pump was placed.

Main Power-Plant.

The main power-plant is on the west side of and opposite the outer end of the train yard, at what was formerly the intersection of I and First Streets, N. E., about 1 200 ft. north of the station. It consists of a masonry and steel structure, 78 ft. wide and 234 ft. long, with an extension, 30 ft. wide and 150 ft. long, at the south end, used as an office building, storeroom, and repair shop.

The west side of this structure is carried down to the street level, and the north, east, and south sides are supported on concrete retaining walls carried up to the track level.

The concrete retaining walls were required to withstand the pressure of the fill deposited in forming the roadbed, which is about 20 ft. above the street level on the west side. On account of unstable material, the foundations were carried 12½ ft. below the basement floor level. The rail grade in the yard practically coincides with the floor level in the boiler-room. The engine-room floor is about 8 ft. below the boiler-room, and the basement is about 2 ft. below the average street level on the west side.

To make the basement story of the power-house and office extension harmonize with the retaining walls north and south of it, the west wall of the building was built of stone laid in courses corresponding in thickness to those used in the retaining walls. Above the height of the retaining walls, the building walls are of brick with Indiana limestone trimmings. The cornice and eaves are of galvanized iron painted to conform to the color of the stone trimmings.

The power-house, except a space at the south end 35 ft. long and of the width of the building, is divided longitudinally by a wall, about 17 in. thick, extending from the basement to the roof, providing a 40-ft. boiler-room on the east side and a 36-ft. engine-room on the west side. The space at the south end is used in connection with the refrigeration plant and water tanks. Space is also set aside for an ice-making plant, which will be provided at some future time.

The basement under the engine-room is 11 ft. high and under the boiler-room 20 ft. The engine-room has a clear height of about 30 ft. to the under side of the roof trusses, providing space for the operation of a traveling crane, the runway rail of which is 23 ft. above the engine-room floor. As the economizers, and coal and ashes bunkers are above the boiler settings, this portion of the building was constructed so as to provide head-room of about 44 ft. to the under side of the roof trusses.

The main roof is of book tile, concrete, and red vitrified Spanish tile; the flat roof over the engine-room is covered with Ehret's slag roofing laid on reinforced concrete roof construction. The building is amply lighted on all sides, each wall panel having a 10 by 18½-ft. window, the sashes in which are in hinged sections with a Pond sash-

operating device. Clerestory windows furnish light and ventilation for the extreme upper portion of the building.

In this plant provision has been made for future growth. The boiler-room will accommodate ten boiler units, though only seven are considered necessary at present. In the engine-room provision is made for six 500-kw. turbo-generators, though four are capable of supplying all needed power at present.

A consideration of the power requirements at the station, in the yard, and at the shops, showed the necessity of a general plant to furnish steam heat for the depot, express building, signal towers, and train yard; electricity for light and power over the entire passenger terminal occupation; compressed air for the operation of switches and signals, testing air brakes on trains at the station, and providing the necessary air cushion in elevator pressure tanks; hydraulic pressure for operating passenger elevators, baggage lifts, and fire service; and refrigeration for the drinking-water system and refrigerators in the restaurant, kitchen, and other service-rooms.

Power-House Stack.—The chimney for the power-house, except the foundation, was built by the Alphons Custodis Chimney Construction Company, of New York, and contains no unusual features. It is 275 ft. high above the foundation, and extends about 200 ft. above the highest point of the roof of the power-house. The base, octagonal in form and 19 ft. high, is laid up in plain hard red brick, the minimum thickness of wall being 40 in. Above this point it is of the usual perforated radial blocks, ranging in length from 4 to $10\frac{5}{8}$ in. The blocks in the lower portion of the work were obtained from Birmingham, Ala., those in the upper portion from Washington, Pa. The work was all laid in a mortar composed of 1 part Portland cement, 2 parts lime, and 4 parts sand.

It has an inside diameter of 16 ft. 8 in. at the base and 11 ft. at the top, the thickness of wall varying from 30 in. at the base to $7\frac{1}{2}$ in. at the top. Starting at a point 16 ft. above the octagonal base, the variations in thickness occur at intervals of 20 ft. throughout the remainder of the height, dividing the stack above this point into twelve sections, which, with the 19-ft. base and 16-ft. section of radial blocks above noted, constitute the fourteen sections into which the total height is divided.

The chimney, to a height of 200 ft., is lined with fire-brick 4 in.

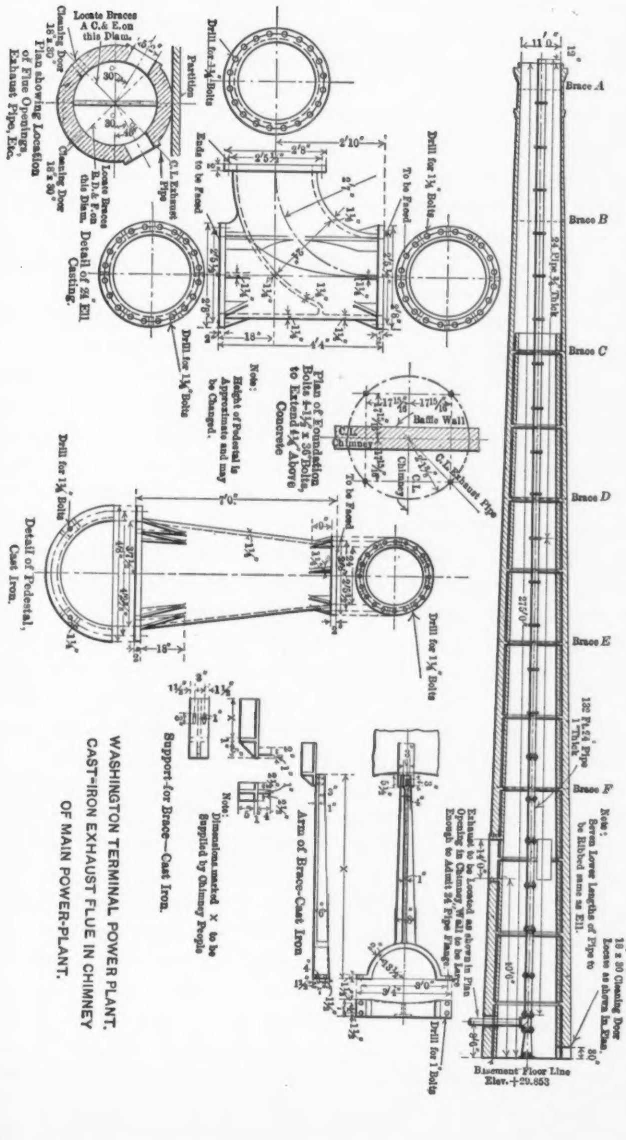


FIG. 5.

WASHINGTON TERMINAL POWER PLANT.
CAST-IRON EXHAUST FLUE IN CHIMNEY OF MAIN POWER-PLANT.

thick, and the lining is divided into sections corresponding to those in the outer wall. Each section of the lining is supported on a corbel or offset formed in the outside brickwork at the section points. There is a 2-in. air space between the 4-in. lining and the outer wall. This sectional construction is the usual Custodis arrangement, the result being greater stability in the chimney and greater ease in making renewals or repairs, as only one section need be disturbed at a time.

The two flue openings, each 5 ft. 2 in. wide and 14 ft. high, are 49 ft. 6 in. above the basement floor, and separated by a 12-in. baffle-wall of brick 21 ft. high, supported on an I-beam platform 46 ft. above the foundation.

The point of special interest in this chimney is the exhaust riser in the center, the top of which extends a short distance above the top of the brickwork. It is constructed of 12-ft. lengths of 24-in. cast-iron pipe with flanged ends and bolted joints. There are twenty-two 12-ft. sections in the pipe column proper, the lower half of which has 1-in. walls, the upper half $\frac{3}{4}$-in. walls. This pipe column is supported on a 7-ft. pedestal having an outside diameter of 4 ft. 8 in. at the base and the same diameter as the pipe at the top, to which is bolted the base elbow, 4 ft. 4 in. long. The pedestal is bolted to the foundation by four 2-in. foundation bolts. The lower seven sections of pipe are reinforced by ribbed flanges similar to the reinforcement of the pedestal and base elbow. For the upper portion of the column there are six sets of cast-iron braces or stays at intervals of from 35 to 40 ft., the lowest one being about 75 ft. above the foundation. Below this point the pipe is sufficiently stayed by the baffle-wall between the flue openings. The cast-iron braces or stays have semicircular straps or bands at one end for bolting to the column, two being used at each of the six points. The outer ends are attached to brackets built in the wall, each pair of braces alternating at right angles with the pair above or below.

The foundation was included in the power-house contract. Before deciding on the style of foundation, test holes were bored to a depth of from 60 to 65 ft. below the original surface of the ground, for the purpose of obtaining some idea of the character of the soil. At a depth of about 15 ft. a great deal of water was encountered, requiring a casing to be driven as the hole was formed. For the first 15 ft. the soil was composed of a mixture of clay and gravel in irregular

layers and pockets. Below this elevation the material was a mixture of very fine sand and blue clay, of a very soapy nature.

In order to make a more thorough examination, a test hole 8 ft. square was started, the sides being shored in a most careful manner. There was no difficulty in excavating the first 16 ft., but, before a depth of 30 ft. was reached, the water and sand were forcing their way into the hole faster than one pump and several men could remove it. On account of the danger of disturbing other foundations by this flow of water and sand, and as the results were similar to those where holes were bored, this test was also abandoned and the hole filled.

The original plan contemplated the use of concrete piles to be put in by the Simplex method. Equipment for this purpose was brought to the site and several test piles were driven. On account of the large quantity of sand in the soil, there was considerable difficulty in driving the tube to the required depth, and, when driven, the contractor had greater difficulty in withdrawing it. It was necessary to begin to remove the tube as soon as the placing of concrete was started, but water and sand forced their way into its lower portion with such speed as to prevent filling it with concrete. In the two or three test piles put down the quantity of concrete used was 15 or 20% less than required, indicating that a portion of the space was filled with water and sand, and as there was no way of determining definitely where it might be located, piles of this kind had to be abandoned.

Owing to the presence of so much sand in the soil, some doubt was expressed as to the possibility of driving a sufficient number of wooden piles to carry the load. After due consideration, wooden piles seemed to be the last resort, and arrangements were made to drive them at intervals of about 3 ft. from center to center. The work was started by driving from the circumference toward the center. This plan was adopted in the hope of getting the best results around the outer edge where the greatest load would result from wind pressure. The displacement of soil was not so great as anticipated, and the piles in place were not disturbed by driving adjacent ones. There was great difficulty, however, in driving them to a safe depth, a large number breaking in the driving. This was especially true in the south half of the foundation. In all, however, 191 pine piles were driven to an average depth of about 25 ft. below the cut-off line. As the load on the founda-

tion, including wind pressure, is about 5 000 tons, each pile under the severest strain must sustain more than 25 tons.

As a protection against lightning, the stack has a lightning rod of ½-in. stranded copper cable terminating at the base of the stack in a coil in the earth and above in a loop extending around the top, to which six retort-graphite points, 5 in. long and 1 in. in diameter, are attached with ¾-in. galvanized-iron pipe and suitable brass sleeves. The connection between the copper cable and the graphite point is made by drilling a ½-in. hole in the end of each point to a depth of 2 in., the copper being held to the graphite by a suitable set-screw. The cable is secured to the side of the chimney by braces and clamps.

Boilers, Super-heaters, and Stokers.—The Babcock and Wilcox Company, of New York, furnished and erected seven semi-marine water-tube boilers, seven super-heaters, and seven chain-grate stokers. The boilers are set singly and supported on concrete-encased girders and beams forming the longitudinal and cross-members of the boiler-room floor system. Each boiler has a heating surface of 4 220 sq. ft. and a rating of 420 h.p. The settings are fashioned after the Dutch oven-furnace construction, with combustion chambers well within them, the tops of which extend about 22 ft. above the boiler-room floor. The tube sections in each unit are inclined at an angle of 15° with the horizontal, and are 14 ft. long. The heating surface consists of 4-in. tubes, arranged in 20 sections, 13 tubes high. The iron casings around the fire-box are bolted to the structural-steel framing forming the sections for each unit, and to the casing plates are fastened the non-conducting linings consisting of ¼-in. asbestos mill-boards, which in turn are protected by light fire-tile.

There is a steam and water drum, 42 in. in diameter and 13 ft. long, of open-hearth steel ½ in. thick, above the front end of each boiler at right angles to the tube sections. The longitudinal seams of the drum are butted and strapped, both inside and out, and are secured by four rows of rivets, two of which extend through both straps and shell plates, the other two extending only through the inside strap and shell. The drum heads are of $\frac{9}{16}$-in. steel plates spherically bumped, the radius of the bump being equal to the diameter of the drum. Each head has an 11 by 15-in. manhole flanged and properly reinforced to provide for gasket not less than 1 in. wide. Each drum is connected with each of the lower front serpentine headers by 4-in.

vertical tubes, and with the rear headers by horizontal tubes of the same size, thus affording twenty independent inlet and outlet connections for steam and water. All attachments for steam and water valves and other fittings are of wrought-steel pads or nozzles securely riveted to the drums.

A mud-drum, consisting of a 6-in., square, forged-steel box, is connected to the lower ends of the front tube headers, for blowing down and draining the system. All pressure parts are of open-hearth steel plate and seamless tubes. All tubes are 4 in. in diameter and No. 9 B.w.g. in thickness, expanded at the ends into wrought-steel headers. Access to the front and rear ends of the boiler tubes is provided by rolling shutter doors.

Each boiler has two 4-in., Coale, muffler safety-valves set to blow at 200 lb., one Ashcroft, 12-in., brass-rimmed gauge graduated to 300 lb., one Babcock and Wilcox, water column, three try-cocks arranged for operating from the fire-room floor, one 2½-in. stop- and check-valve, two 2½-in., Babcock and Wilcox, bottom-blow valves, together with wrenches, tube-cleaners, steam-hose, and cleaning pipe for removing soot from the exterior of the tubes. All tube sections and steam- and water-drums were designed to stand a test under water pressure of 300 lb. per sq. in. with a working pressure of 200 lb.

Each boiler unit is fitted with a Babcock and Wilcox superheater above the incline tube sections, to the rear of the smoke uptake. It is composed of 2-in., seamless, U-shaped tubes expanded at the ends into wrought-steel box headers. The steam is piped from the steam-drum to the lower superheater header at the rear with delivery connection on the other header. Each superheater is composed of 76 tubes, presenting a heating surface of 695 sq. ft., and designed to raise the temperature of steam 100° Fahr. above that of saturation. There is a safety-valve for each heater on the discharge side, set to blow below the safety-valves on the boilers. The main steam outlet is 6 in. in diameter. The regulation of superheat is facilitated by dampers located so as to control the passage of gases, by shunting part of them below the heater when necessary. The dampers are operated by drum and wire rope, the apparatus being controlled from the outside.

Each boiler has a Babcock and Wilcox, chain-grate stoker, 8½ ft. wide and 10 ft. long, operated by a line shaft under the boiler-room

floor, to which the stokers are connected by detachable gear. The power is furnished by two vertical, slide-valve engines in the basement under the boiler-room floor. The line shaft can be operated by one or both engines by the use of clutches. Each grate has an area of 85 sq. ft., or approximately 1 sq. ft. of grate area to 50 sq. ft. of boiler heating surface. Coal is delivered to the stokers by down-spouts from the storage bunkers in the upper portion of the boiler-room. The bunkers are of reinforced concrete, there being a continuous line, except opposite the chimney, the entire length of the building. Each bunker is 5½ by 10 by 14 ft., and the entire layout has a capacity of 600 tons. In the section opposite the chimney, occupying a space 32 ft. long, are located the ashes bunkers, the bottoms of which slope outward instead of inward as do the coal bunkers. There are two delivery spouts for chuting the ashes into cars on the track outside the building.

Economizers.—The Green Fuel Economizer Company, of Matteawan, N. Y., furnished and put in seven improved patent fuel economizers, containing 8 084 sq. ft. of heating surface, one over each boiler unit, through which the furnace gases pass in reaching the main chimney breeching.

Each economizer consists of sixteen sections of 4-in. tubes, each section composed of six tubes 9 ft. long, connected at top and bottom by headers, in which the ends of the tubes are turned and pressed by hydraulic machinery. The top headers are planed and fitted to insure air-tight joints, and have hand-hole lids opposite the vertical tubes to facilitate cleaning and making repairs. Outlet and inlet branches have access lids for cleaning the bottom headers.

Each unit has a heating surface of 1 152 sq. ft., a trifle more than one-fourth that of the boiler unit, and was constructed to stand a test of 350 lb. per sq. in. at the works, or 200 lb. per sq. in. hydraulic pressure after erection at the plant. Each economizer has a 2-in. safety-valve, the necessary cast-iron soot-pit frames, air-tight doors, and side-dampers. Each unit has improved scraper gears, the line shafts for operating them being attached to the edge of the coal bunkers. They are divided into two groups, respectively, north and south of the stack. Each group is operated by a 10-h.p. motor. The north group at present contains four units, the south group three. Each line shaft is designed to take care of five units eventually.

The economizer units are supported on a steel framework over the boiler units, and are enclosed with steel plates lined with fire-brick, instead of the usual brick enclosures. The rear end of the economizer connects directly with the main breeching; the front end connects directly with the uptake from the boiler which leaves from the front side of the boiler setting.

The breeching connecting the boilers with the stack is divided into two sections, one taking care of the boilers on the north side of the stack, the other those on the south. It consists of a horizontal duct of $\frac{3}{16}$-in. steel plates, 4 ft. 9 in. by 9 ft. 9 in. in section, lined with $2\frac{1}{2}$-in. magnesia blocks coated with $\frac{1}{2}$ in. of retort cement furnished by The Philip Carey Company, of Cincinnati, Ohio. The Patterson Manufacturing Company, of Baltimore, Md., placed in each section of the breeching a hydraulic damper regulator, which is controlled by the steam pressure.

Feed-Water Heaters.—The Harrison Safety Boiler Works furnished and erected two No. 334, Cochrane, special, feed-water heaters and receivers, including the Sorge-Cochrane system of water purification. Each heater is 139 in. wide, 78 in. deep from front to back, and 105 in. high. In each heater there are 20 perforated trays, 12 in. wide and 36 in. long, and a filter bed, 36 in. wide and 72 in. long. The exhaust inlet and outlet are 14 in. in diameter, the cold water supply 4 in., the pump suction 8 in., the waste or overflow 4 in., and the gravity returns 8 in. This apparatus is especially designed and adapted for use with any steam heating or drying system, under vacuum or back-pressure. In addition to performing the regular functions of an open or direct-contact feed-water heater, it provides for the reception and heating of the condensation from the heating system. The supply of cold water, to supplement the exhaust condensed in the heater and the condensation from the heating system, is regulated automatically. The drip from the oil separator and the overflow from the heater are carried to waste through a steam-trap forming part of the heater.

All parts exposed to water or escaping gases are of cast iron, brass, and copper. The oil separator, attached to the shell and forming part of each heater, is a most efficient device for removing cylinder oil from exhaust steam, and is designed and proportioned for a normal steam velocity of 6 000 ft. per min. through engine ports and steam pipes. The perforated trays are in the upper part of the heater, and are inter-

changeable and removable. They are inclined in alternate directions, and the edges over which the water flows are serrated for breaking it up. They are secured in place by cast-iron guides bolted to the shell of the heater in such a way as to prevent them from being dislodged by the pulsations of the exhaust. Each set of trays is in the steam space, with passages between the trays and tray supports giving a greater area for steam than the inlet opening, thus bringing the steam into contact with the water as it flows from tray to tray. After passing through the regulating valve, the cold water is conveyed by pipe to a box or trough extending across the trays, from which it falls through openings to the upper trays, across which it flows, dropping to the one below, and so on, until it reaches the bottom one, from which it drops into the settling chamber in the lower part of the heater. The flow of cold water is regulated by a balanced valve controlled by a ventilated copper float in the heater. Any change in the level of the water raises or lowers the float, thus opening or closing the valve and supplying water in proportion to the quantity taken from the heater by the boiler-feed pump, and preventing waste by overflow.

A skimmer, just above the working level of the water and extending the width of the heater, removes the impurities which rise to the surface of the water. To take care of additional refuse matter, all Cochrane heaters have perforated plates, about 4 in. above the bottom of the heater, upon which is placed the filtering material. The outlet to the pump is covered with a hood, extending to the perforated plates, open at the bottom and vented at the top by a pipe to prevent air-logging and consequent interference with the pump suction. It also prevents the siphoning of water from the heater, and maintains a seal for keeping the floating impurities from the pump suction. The hood insures the passage of all water through the filter.

The gravity returns are brought into the heater by a specially designed trough which forms a water seal for the return pipe and prevents the escape of steam from the heater into the heating system. Thus the water of condensation is brought into contact with exhaust steam in the heater, which insures the same temperature as the water in the pool. Returns from the vacuum pumps are taken into the heater through the cold-water pipe by special connection between the heater and the regulating valve.

These heaters are guaranteed to separate the cylinder oil (carried

in the exhaust steam) from the water, making it suitable for boiler feed and other purposes; and, if given a sufficient supply of exhaust steam, will deliver feed-water at a temperature within from 2 to 5° of the temperature of the steam entering the heater.

They will give all purification which can be obtained by heating water to the temperature of exhaust steam, by providing large filtering and settling surfaces and utilizing the steam condensed in heating the water, and will provide for the reception and heating of water condensed in the heating system, the return being made by gravity or pumped into the heater. They will control the cold-water supply automatically, so that no cold water will be introduced into the heater until the returns from the heating system are found insufficient to meet the demand, and the steam leaving the heater will be freer from water than when leaving the engines.

Each heater is designed to raise the temperature of 60 000 lb. of water per hour from 60° to 210° Fahr. The main source of steam supply is the exhaust main serving the air compressors, elevator pumps, and auxiliary engines in the plant.

Pumps.—The Epping-Carpenter Company, of Pittsburg, Pa., furnished and erected, on foundations provided by the Terminal Company, two 16 by 10 by 16-in., duplex, outside, end-packed, pressure-pattern, boiler-feed pumps, two 12 by 8 by 16-in., duplex, outside, end-packed, pressure-pattern, boiler-feed pumps for building service, and two 18 by 10 by 12-in., underwriter fire-pumps by the George F. Blake Manufacturing Company. In all these pumps the water-cylinder stuffing-boxes and glands are bronze-lined. Each pump has a 2-qt. Richardson oil pump.

The boiler-feed pumps have 8-in. suction and 6-in. delivery nozzles, for water connections with 3-in. steam supply and 4-in. exhaust, and are capable of delivering 600 gal. of water per min. at a piston speed of 75 ft. and 300 lb. pressure. The building-service pumps have 6-in. suction and 5-in. delivery nozzles, for water connections with 2½-in. steam supply and 3-in. exhaust, and are each capable of furnishing 350 gal. per min. at a piston speed of 67 ft. and 300 lb. pressure. The fire-pumps have 12-in. suction and 8-in. discharge nozzles, for water connections with 4-in. steam supply and 5-in. exhaust, and are each capable of delivering 1 000 gal. per min.

Pumping Engines.—The Nordberg Manufacturing Company, of

Milwaukee, Wis., furnished and erected two horizontal, heavy-duty, cross-compound, non-condensing, Nordberg, poppet-valve, pumping engines, with cylinders 12 by 21½ in. and plungers 5¾ in. in diameter, having a common stroke of 24 in. When running at a piston speed of 300 ft. per min., or 75 revolutions, under a steam pressure of 150 lb. at the throttle, with 100° Fahr. superheated steam, these engines will pump 750 gal. per min. against a pressure of 300 lb., with a suction pressure of 40 lb.

Under the foregoing conditions, the steam consumption will not exceed 1 000 lb. of dry steam containing 100° Fahr. superheat for every 85 000 000 ft-lb. of work done; and, when the steam contains 50° Fahr. superheat, the steam consumption will not exceed 1 000 lb. for every 75 000 000 ft-lb.

The pumps consist of two cylindrical chambers, containing seats for delivery and suction valves, which are located one above the other. There is one pressure air chamber above each side of the pump. Each pump rests on, and is bolted to, a cast-iron suction base.

The two chambers are connected firmly by removable distance-rods located in a plane passing through the center line of the engine, and by the delivery and suction immediately above and below the same. The chamber nearest the steam cylinder is connected to it by similar rods, making the engine self-contained. The stuffing-boxes and plunger-rods are lined with brass, and the valve faces with leather. The valve seat has a central spindle which passes through and guides the valve, the lift of which is controlled by a spring, and has an area of 40 sq. in. for both suction and discharge.

The frames are of the heavy-duty type, and cast in one piece. The flange (on which the cylinder head is centered) and the slides were bored at one setting, insuring perfect alignment. The base extends the full length of the frame, and has up-turned edges for catching oil. The steam cylinders are jacketed all over, including the heads, and are cast with double walls to provide a steam jacket. The cylinders are fitted with Nordberg, poppet-valve gear, each cylinder having four equilibrium poppet-valves, the steam inlet-valves being on top and the exhaust at the bottom of the cylinder.

Coal and Ashes Handling Apparatus.—The C. W. Hunt Company, of New York, furnished and erected a Hunt coal and ashes handling equipment, comprising a conveyor consisting of buckets, chains, tracks

and supporting stands, curves, take-up, chain-guard, and dumpers; a conveyor driver having a two-cylinder steam engine, geared for 150 lb. steam pressure; and two steam-driven, direct-connected coal crackers, with two cross-belt conveyors for carrying coal from the crackers to the Hunt conveyor.

The coal is delivered at the plant in regular, drop-bottom, coal cars, from which it is dumped into a hopper having a capacity of about 50 tons, located under the track on the east side of the building. From this hopper the coal passes through the crackers and thence by belt conveyors to the bucket conveyor, to be stored in the bunkers in the upper part of the boiler-room.

The coal is delivered to the bucket conveyor by a rotary filler, which insures a uniform and even supply. In delivering the coal to the bunkers, the conveyors have a lift of 62 ft., a speed of about 40 ft. per min., and a capacity of about 60 tons per hour.

The dumpers are placed at intervals along the upper run of the conveyor, and are easily thrown in and out of gear by the operator. The ashes are delivered to the ashes bunkers by the same conveyor. To permit this being done, there are reinforced concrete pockets under each chain grate, in which the ashes are collected. At the bottom of these hoppers there are reinforced concrete spouts or chutes through which the ashes are chuted to the conveyor and thence carried to the ashes bunkers. The ashes are taken from the bunkers by chutes leading through the east wall of the building, from which they are delivered to cars on the siding used for the delivery of coal, the same cars being used for both coal and ashes.

Air Compressors.—The Nordberg Manufacturing Company furnished and erected, on foundations constructed by the Terminal Company, two cross-compound, two-stage, Nordberg-Corliss, air compressors, with such necessary appurtenances as steam receivers, intercoolers, etc., ready for steam, air, and exhaust connections. The steam cylinders are 14 and 24 in. in diameter, and the air cylinders 14½ and 24½ in., with a common stroke of 32 in.

The frames are of the heavy-duty type, having main bearing and slide in one casting, and resting on a base extending the full length of the frame. There is a heavily-ribbed, cast-iron, foundation plate extending under the air and steam cylinders. The fly-wheels are 10 ft. in diameter, and weigh 23 000 lb. The cylinders are tapped for an

indicator, and polished brass pipe and valves are provided with a central T for attaching the indicator. There is a pressure regulator which maintains automatically a constant pressure of air by varying the speed of the engine. The governor is driven by a belt from the engine shaft. The air cylinders are of re-melted iron, cast in dry sand, and are water-jacketed on barrels and heads, insuring regular cooling throughout.

The steam cylinders are placed behind their respective air cylinders, and are fitted with the regular Nordberg-Corliss valves and valve gear, the high-pressure cut-off being under control of a combined speed and pressure regulator. A receiver, of the re-heater type, under the floor, is fitted with a pop safety-valve set at 50 lb. to prevent the low-pressure cylinder from being over-strained from excessive pressure.

There is a tubular inter-cooler, above and between the air cylinders, fitted with seamless, drawn-brass tubes, providing 450 sq. ft. of cooling surface, or ample to cool the air discharged from the low-pressure cylinder.

Each machine has a complete oiling system, comprising a hand pump for each cylinder, a trombone oiler for the cross-head pins, Nugent oilers for the crank pins, and Richardson forced-feed pumps for each steam cylinder, driven from a suitable place on the valve gear; all other working parts have suitable funnels connected with an elevated tank by piping. There are oil guards, of planished steel with polished corner strips, around the cranks and eccentrics, and properly tapped for the drainage of oil.

Each compressor has two Crosby, steam-engine indicators, one 100-lb. spring, one 80-lb. spring, and two 30-lb. springs, together with the following gauges: One air pressure, one steam pressure, one air pressure for inter-cooler, one compound for receiver, and one six-point counter, all with 8½-in. nickel-plated dials.

These machines furnish compressed air, at about 100 lb., for the operation of the electro-pneumatic signals connected with the New York Avenue, K Street, and Massachusetts Avenue interlocking plants, and for testing air brakes on passenger cars in the train yard. They also furnish the Franklin-type compressors with air at from 100 to 120 lb., which is in turn compressed to about 300 lb. for use in the hydraulic elevator system. When operating at 460 ft. piston speed, or about 86 rev. per min., non-condensing, with steam at 150 lb. pressure

and 100° Fahr. superheat at the throttle, and back-pressure not exceeding 1 lb. at the nozzle of the low-pressure cylinder, they compress 1 500 cu. ft. of free air per min. to 100 lb. pressure. When running under the foregoing conditions the steam consumption should not exceed 5.8 lb. for each 100 cu. ft. of air compressed.

The Chicago Pneumatic Tool Company furnished two special, Franklin-type, class G-SS, single, steam-driven, air compressors, each having a capacity of 50 cu. ft. of free air per min., and capable of delivering compressed air under 320 lb. pressure. The steam cylinders are 8 in. in diameter, with a 12-in. stroke, and are designed for a steam pressure of 150 lb. with steam superheated 100° Fahr. The air cylinders are 6¼ in. in diameter, with a 12-in. stroke, and receive the air supply from the Nordberg compressors at from 100 to 120 lb. pressure, compressing it to about 300 lb. per sq. in. for use as a cushion in the pressure tanks of the hydraulic elevator system.

These compressors have single, straight-line, steam and air cylinders, and operate at 120 rev. per min. The cylinders and heads are completely water-jacketed, and are designed for thorough circulation, thus affording equal cooling throughout. They are provided with a pressure-regulating governor which controls automatically the operation of the compressor in accordance with the demand for air, working in conjunction with a speed governor which regulates the speed of the compressor. There is also an unloading device for relieving the compressor of all load when the desired pressure is obtained and causing it to resume delivery automatically when the receiver pressure is reduced.

These machines are assembled, aligned, and tested at the factory on a common base, and are shipped in one piece. Unless damaged in transit, there is no difficulty in putting them on foundations and getting them ready for service.

Turbo-Generators.—The Westinghouse Machine Company, of Pittsburg, Pa., furnished and erected four 500-kw., Westinghouse-Parsons, turbo-generator units, on foundations built by the Terminal Company. The steam turbine is known as the multiple-expansion, parallel-flow type, adapted for driving a direct-connected generator with a two-pole, revolving field, running at 3 600 rev. per min., and giving 7 200 alternations per min. The turbine and generator are mounted on a continuous bed-plate having suitable supports for turbine, generator, generator bearings, etc.

The condenser for each turbine is in the basement directly beneath it. They are of the Worthington surface type, with cast-iron cylindrical shells, and contain 1 600 sq. ft. of condensing surface. The condensing water is taken from the cooling tower, and circulated by 14-in., volute, centrifugal pumps.

The maximum length of turbine is 12 ft. 7 in.; the combined unit, 21 ft.; width, 4 ft. 5 in.; height above floor, 6 ft. 7 in.; approximate weight, 25 000 lb. Its capacity is 750 b.h.p. when operating at 3 600 rev. per min., with dry saturated steam of 150 lb. gauge pressure per sq. in. at the throttle, and with a pressure in the exhaust pipe of 25 in. vacuum, measured by a mercury column referred to a barometric pressure of 30 in. The contract provides that the steam consumption, including all steam consumed by the turbine and all leakages and losses, will not exceed the following quantities per British horse-power-hour when operating under the above conditions:

	25-in. vacuum.	26-in. vacuum.	27-in. vacuum.
Full load........	16.3 lb.	15.6 lb.	15.1 lb.
¾ "	17.2 "	16.4 "	15.7 "
½ "	19.0 "	17.9 "	17.0 "
1¼ "	16.7 "	16.0 "	15.5 "
1½ "	18.3 "	17.3 "	16.7 "

When operating at the foregoing speed and steam pressure, but with a back-pressure in the exhaust pipe of 1 lb. and ½ lb., respectively, the steam consumption per British horse-power-hour will be as follows:

	1 lb.	½ lb.
Full load..............	34.3	33.9
¾ "	36.6	36.0
½ "	41.2	40.3

When operating at 3 600 rev. per min. with 150 lb. pressure at the throttle, but with steam superheated 100° Fahr. above the temperature of saturated steam, the steam consumption will not exceed the following quantities per British horse-power-hour:

	25-in. vacuum.	26-in. vacuum.	27-in. vacuum.
Full load........	14.7 lb.	14.1 lb.	13.6 lb.
¾ "	15.5 "	14.8 "	14.1 "
½ "	17.1 "	16.1 "	15.3 "
1¼ "	15.0 "	14.6 "	14.0 "
1½ "	16.5 "	15.6 "	15.1 "

When operating under such conditions, but with a back-pressure on the exhaust pipe of 1 lb. and ½ lb., respectively, the steam consumption will be as follows:

	1 lb.	½ lb.
Full load..............	30.9	30.5
¾ "	32.9	32.4
½ "	37.1	36.3

Each turbine has a secondary governor-valve of the balanced, poppet-valve type, with which an overload of 50% may be developed, or a full load developed when operated without the condenser. This valve is operated automatically by a suitable mechanism in connection with the governor, and is arranged to open when the load exceeds the amount the turbine can carry when operating normally. It will also operate should the vacuum or steam pressure fall to a point where the turbine is unable to carry the load normally, and will return to its seat automatically when the excess capacity of the turbine is no longer required. The speed is controlled by a sensitive governor operated by varying the admission of steam. The governor has an electrical speed-change device operated by motor.

The turbines are lubricated by a continuous circulation of oil supplied by a system of delivery and drain pipes, with a suitable reservoir in the bed-plate. A pump, driven by the turbine, together with a cooling coil, is furnished with each turbine.

The alternating-current generator is of the turbo type, and has two poles. The normal speed is 3 600 rev. per min., the frequency is 7 200 alternations or 60 cycles per sec., delivering three-phase current at 2 300 volts. The normal rating of the generator is 125.5 amperes per terminal at 2 300 volts and 100% power factor.

The efficiencies for these generators, based on the C^2R losses, armature iron loss at the normal rated current and voltage, and 100% power factor, are 92% at one-half load, 94% at three-quarters load, 95% at full load, 95.5% at one and one-quarter load, and 95.75% at one and one-half load. The generator is separately excited. When the generator delivers its normal rated current at normal voltage and 100% power factor, the field requires approximately 75 amperes at 100 volts, or 90 amperes when delivering its normal rated current at normal voltage and 90% power factor.

The armature is of the slotted-drum type, the core being built up of laminated steel of high magnetic quality. The armature winding

consists of wire-wound coils, formed and insulated before being placed in the slots. The insulation of the conductors consists of material of high insulating quality applied in overlapping layers treated with moist and oil-proof compound. When completed, the insulation of the armature winding from the core was subjected to a momentary puncture test of 5 000 volts, alternating e.m.f.

The field core is of steel. The steel pole pieces and field winding are proportioned so as to reduce the armature reaction and self-induction to a low limit. The field coils are wound with strap copper, and are insulated from the core by layers of fibrous material. When completed, the insulation of the coils from the core was subjected to a momentary puncture test of 1 000 volts, alternating e.m.f.

The field winding is proportioned so that, with constant speed, constant separate excitation, and 100% power factor, the load may vary from full load to no load with a rise in voltage of approximately 10 per cent. The constant voltage is maintained by a Tyrill regulator.

The temperature in any part of the generator will not rise more than 40° cent. in 24 hours when delivering its normal current at normal voltage and 90 to 100% power factor, or more than 55° cent. with 25% greater current but the same voltage and power factor.

Cooling Tower and Surface Condenser Equipment.—Henry R. Worthington, of New York, furnished and erected, on foundations provided by the Terminal Company, a cooling tower and the necessary surface-condensing equipment for the power-house. The cooling tower is of brick on a concrete foundation, and is immediately north of the power-house. It has an inside diameter of 28 ft., a height of 38 ft. above the foundation, and contains about 12 000, 6-in., salt-glazed tiles, 24 in. long, with walls 1 in. thick, presenting a cooling surface of about 91 500 sq. ft.

The terra cotta baffles are built up in eight courses, the tiles standing on end, each course containing 1 490 tiles, making a stack 16 ft. high. The support for these baffles is 13 ft. above the foundation, and consists of I-beams, ranging from 18 to 24 in. in depth, spaced at 2½-ft. centers, built into the outer shell. Resting on the tops of these I-beams is a wrought-iron grating of ½ by 2½-in. flat bars, spaced at 5½-in. centers, separated by 5-in. sections of ½-in. wrought-iron pipe, secured by ⅜-in. bolts.

It is equipped for forced-air circulation with four 96-in. disk fans,

driven in pairs by two 40-h.p. Westinghouse induction motors. The fans operate at 350 rev. per min., requiring 64 b.h.p. for each pair. It is capable of cooling the circulating water required to condense 30 000 lb. of steam per hour and maintain in the condensing apparatus a 26-in. vacuum on 30-in. barometer, with prevailing atmospheric conditions of 75° temperature and 75% relative humidity.

In the base or concrete foundation of the cooling tower there is a cistern or tank, 23 ft. in diameter and 11 ft. deep, for taking care of the cooled water, the side-walls and bottom of which were water-proofed with hydrolithic compound by the E. J. Winslow Company, of Chicago.

The circulating water is delivered near the top of the tower by a vertical, 18-in., cast-iron pipe in the center, and is distributed by eight perforated pipes attached at right angles to a cap at the top of the pipe, equally spaced over the area at the top of the tower. From these arms it falls to the tank. This pipe connects with the 24-in. discharge main near the bottom of the foundation, or 3 ft. 4 in. below the basement floor level.

The return to the condensing apparatus is a 24-in. cast-iron pipe, laid beside the discharge pipe, connecting with the cistern about 2 ft. above the bottom. There is a 3-in. cold-water supply pipe by which the water in the tank can be maintained at a regular level. Connecting with the sewer there is an 8-in., cast-iron, overflow pipe, the top of which is 6 in. below the top of the cistern.

The condensing apparatus, immediately beneath the turbines, consists of four 1 600-sq. ft. surface condensers, one for each turbine, two 8 by 16 by 12-in. vertical, single, double-acting, air pumps of the suction, valveless type, two 14-in., horizontal, special, volute, centrifugal, circulating pumps, and two 7½ by 7½ by 6-in., horizontal, duplex, low-service, piston-pattern pumps.

The condensers have cylindrical shells, of close-grained cast iron, with proper openings for exhaust, air, and circulating pipe connections, together with openings for cleaning and inspection. Baffle-plates distribute the steam and relieve the tubes of its impact. The tubes are of seamless, drawn brass, and are required to stand an internal cold-water test pressure of at least 500 lb.; they are in straight lengths, without upset or flanges, and pass through stuffing-boxes in the heads of the tubes. The stuffing-boxes have brass ferrules with a

lip on the inside, for the purpose of securing the tube in position, and to prevent creeping, at the same time allowing freedom for expansion and contraction. By this arrangement any tube can be removed and any stuffing-box can be repacked in case of failure or leakage from long use.

Each circulating pump is capable of delivering 4 400 gal. of water per min. against a dynamic head of 50 ft., when operated at a speed not exceeding 325 rev. per min. The suction openings are 16 in. in diameter and the discharge openings 14 in. They are direct-connected, and are mounted on a common bed-plate with one 10 by 18 by 10-in., Westinghouse, compound engine, the two machines forming a self-contained unit. Each engine and air pump has a Richardson pump lubricator with a tank capacity of 0.8 gal.

The apparatus is arranged so that each turbine has an individual condenser. The vacuum pumps are arranged and proportioned so that each will take care of two units. The service or hot-well pumps are proportioned so that each can take care of the entire load of the four turbines, or 48 000 lb. of steam per hour. Under proper working conditions, each condenser is capable of maintaining a vacuum of 26 in., based on a 30-in. barometer, when each turbine is delivering to its condenser 12 000 lb. of steam per hour, provided a sufficient quantity of circulating water is furnished at a temperature not exceeding 85° Fahr. All steam-driven apparatus is constructed for a steam pressure of 150 lb. with superheat not exceeding 100° Fahr.

Electrical Equipment.—The Westinghouse Electric and Manufacturing Company, of Pittsburg, Pa., furnished and erected, on foundations built by the Terminal Company, the following electrical equipment: One alternating-current switch-board, one direct-current, exciter switch-board in the center of the room, one direct-current, Brush-arc switch-board at the south end of the room, one set of portable testing instruments, one 35-kw., engine-driven exciter, with engine, two 50-kw., motor-driven exciters, with motors, four sets of motor-driven, Brush-arc machines, each set consisting of one 200-h.p., induction motor, direct-connected to two No. 12-B, Brush-arc generators, two 10-h.p., CCL motors, one 10-kw., motor-driven, generator set, and two switch-boards for storage-battery charging sets, the latter located in the basement of the depot.

The alternating-current switch-board controls four 500-kw., 2 300-

volt., 3-phase, 60-cycle, turbine-driven generators, nine 3-phase, power circuits, and six single-phase, lighting circuits. There is a high-tension bus-bar and switch compartment of reinforced concrete in the basement of the power-house directly under the switch-board. There are two extra, generator, switch compartments, four extra, 3-phase, power, switch compartments, and two extra, single-phase, lighting, switch compartments to take care of the future extension of the equipment. There are also the necessary soapstone barriers for the disconnecting switches. All disconnecting and oil switches have a capacity of 300 amperes, the oil switches being distant-control, operated electrically by switch on the main switch-board.

The board consists of nine panels of blue Vermont marble, 16 in. wide, 90 in. high, and 2 in. thick, made in two sections, the upper section 65 in. long, the lower section 25 in. long, furnished complete with angle-iron frames, bus-bars, and supports. Panels 1, 2, 3, and 4 control the 500-kw., alternating-current, 3-phase, 60-cycle, 2 300-volt generators; Panels 5, 6, and 7 control the 3-phase, power feeders, and Panels 8 and 9 control the single-phase, lighting feeders. On each side of Panels 1, 2, 3, and 4 are mounted one polyphase, indicating, wattmeter, two type-F, alternating-current ammeters, one polyphase, integrating wattmeter, one 8-point, voltmeter, receptacle, and plug, one synchronizing plug, receptacle, and indicating lamp, one turbine governor controller and indicating lamp, one rheostat controller with indicating lamp, one oil, circuit-breaker controller with indicating lamp, and one field-switch with discharge resistance. On Panels 5, 6, and 7, controlling nine 3-phase, power feeders, there are mounted, for each feeder, one polyphase, indicating wattmeter and one oil, circuit-breaker controller with indicating lamp. On Panels 8 and 9, controlling six single-phase, lighting feeders, there are mounted, for each feeder, one type-F, alternating-current ammeter, and one oil circuit-breaker controller and indicating lamp. On a swinging bracket at the end of the board there are two illuminated-dial, alternating-current, type-G, voltmeters.

In the basement there are: in connection with each of Panels 1, 2, 3, and 4, one 300-ampere, 2 300-volt, 3-phase, type-F, oil switch, with tripping coil, one polyphase, reversed-current relay, six 300-ampere, 2 300-volt, single-phase, single-throw, disconnecting switches, and one electrically-operated, rheostat face-plate; with Panels 5, 6, and

7, for each feeder, one 300-ampere, 2 300-volt, 3-phase, single-throw, automatic, type-F, oil circuit-breaker, and six 300-ampere, 2 300-volt, single-pole, single-throw, disconnecting switches; and with Panels 8 and 9, for each feeder, one 300-ampere, 2 300-volt, two-pole, single-throw, automatic, type-F, oil circuit-breaker, and six 300-ampere, 2 300-volt, single-throw, single-pole, disconnecting switches.

The direct-current, exciter switch-board controls one 35-kw., 125-volt, direct-current, engine-driven generator, two 50-kw., 125-volt, direct-current, motor-driven generators, and three 300-ampere, 125-volt, direct-current feeders. The board consists of five panels of blue Vermont marble, 16 in. wide, 90 in. high, and 2 in. thick, made in two sections, the upper section 65 in. long and the lower one 25 in. long, with the necessary angle-iron frame, bus-bars, and supports. On the first or regular panel are mounted one 150-volt, type-D, direct-current, voltmeter, one 6-point, voltmeter, receptacle, and plug, mounting for one Tyrill regulator, and swinging bracket at the right of the panel for one 150-volt, type-D, voltmeter. On each of Panels 2 and 3, or 50-kw. generator panels, are mounted one 600-ampere, type-D, direct-current ammeter, one field rheostat, one 4-point, volt meter, receptacle, and plug, one 600-ampere, 250-volt, three-pole, double-throw, type-D switch, and one Thomas, 400-ampere, 125-volt, recording wattmeter. On the fourth, or 35-kw. generator, panel are mounted one 400-ampere, type-D, direct-current ammeter, one field rheostat, one 4-point, voltmeter, receptacle, and plug, one 600-ampere, 250-volt, three-pole, double-throw, type-D switch, and one Thompson, 300-ampere, 125-volt, recording wattmeter. On the fifth or feeder panel are mounted three 200-ampere, two-pole, single-throw, type-C, laminated, carbon-brake circuit-breakers, with low voltage release.

The direct-current, Brush-arc switch-board controls four pairs of motor-driven, 12-B, circuit, Brush-arc generators. The panels are 32 in. wide, 90 in. long, and 2 in. thick, with necessary angle-iron frames, bus-bars, and supports. Each panel has one direct-current, station ammeter, three voltmeter receptacles, four card-holders, one name plate, eight ammeter jack receptacles and plugs, eight cable-transfer receptacles, and fifty-four transfer bus receptacles. In connection with each panel there is provided on swinging brackets one 300-volt, T.I.D., voltmeter, with multiplier, four 5-ft., transfer cables, with two plugs each, and one 10-ft. ammeter cable and plug. Rubber

mats, 2 ft. 9 in. wide and the full length of the switch-board, are provided with each of the boards.

The following portable testing instruments were provided with the equipment: One Westinghouse, alternating-current ammeter of 2½ and 5 amperes capacity; two Westinghouse, alternating-current ammeters with capacities of 5 and 10 amperes; one Westinghouse, polyphase indicating wattmeter, potential capacity 200 to 400 volts, current capacity 5 and 10 amperes; two Westinghouse, series transformers, capacity 25, 50, and 100 amperes; two potential transformers, 2 200-110 volts; one Weston, direct-current, voltmeter, scale 0 to 150; one Weston, millivolt meter, scale 150 to 300; one Weston, portable shunt, 150-15 amperes; one Weston portable shunt, 600-300 amperes; one Weston, alternating-current, voltmeter, 150-300 volts; one magneto, 25 000 ohms; and high-potential, testing transformer, capacity 5 kw., range 100-10 000 volts.

The engine-driven exciter consists of an 8-in., compound, Westinghouse engine, operating at a speed of 375 rev. per min., and having a normal rating of 55 i.h.p., with a maximum of 84 i.h.p. at 150 lb. steam pressure, direct-connected to a 35-kw., direct-current, compound-wound, engine-type generator, operating at 125 volts and 375 rev. per min. The motor-driven exciters consist of a 75-h.p., type-C, three-phase, 2 200-volt, 60-cycle, induction motor, and a 50-kw., direct-current, compound-wound, 125-volt generator, operating at 685 rev. per min., mounted on a common shaft and bed-plate.

The motor-driven, Brush-arc sets consist of a 200-h.p., 125-light, 2 200-volt, 3-phase, 60-cycle, induction motor, direct-connected to two 12-B, Brush-arc machines, complete with couplings mounted on a common wood base, the motor having an oil-immersed auto-starter of capacity to start at no load. The 10-h.p., CCL motors are 60-cycle, 220-volt, induction motors, operating at 850 rev. per min., with oil-immersed auto-starter and slide rails. The 10-kw. motor-generator set consists of a 10-kw., direct-current, compound-wound generator, operating at 125 volts at 1 120 rev. per min., and a 15-h.p., CCL, 220-volt, 1 120-rev. per min., 60-cycle, induction motor, mounted on a common shaft and bed-plate. The motor has an oil-immersed auto-starter, and the generator is furnished complete with a field rheostat.

The switch-boards for battery charging, in the concourse basement, are arranged as follows: No. 1 consists of three panels of blue Vermont

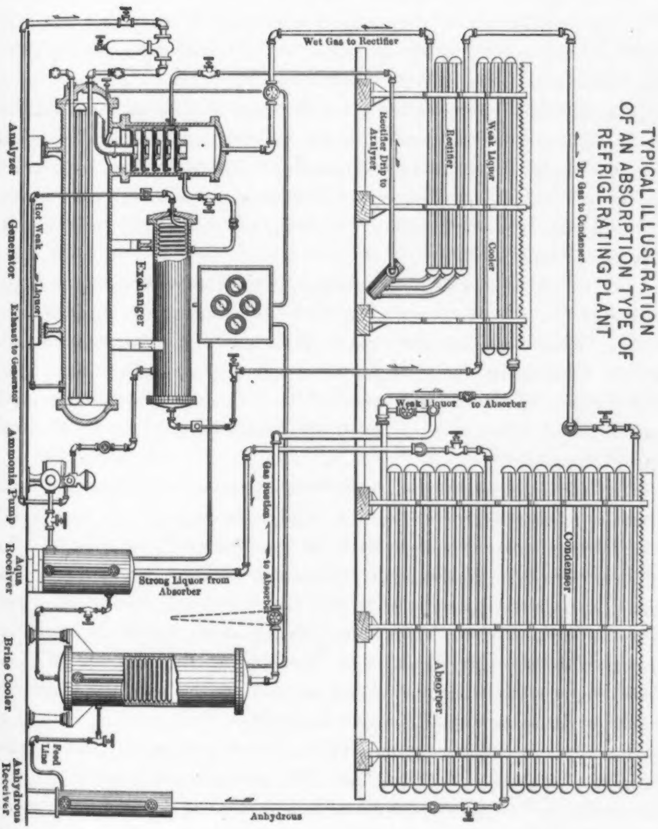
marble, each panel 24 in. wide, 90 in. high, and 2 in. thick, divided into two sections, the upper 65 in. long and the lower 25 in. Panel 1 controls ten 100-ampere, regulating circuits, each taking care of a range in voltage of 60 volts, and has mounted upon it the following apparatus: Ten 100-ampere, 7-point, drum controllers, ten 100-ampere single-pole, double-throw knife-switches, and one 20-point, voltmeter receptacle, while on the back there are ten 100-ampere, enclosed fuses. Panels 2 and 3 are arranged to take care of 30 charging circuits of about 75 amperes each, and have the following apparatus mounted on each: 30 Anderson charging receptacles, 30 lamp brackets, and 30 5-c.p., 110-volt, incandescent lamps. Supplied with the panels are 10 Anderson charging plugs, each with 8 ft. of flexible cable. On swinging brackets at the ends of these panels there are one 150-volt, illuminated-dial, direct-current, voltmeter, and one 150-ampere, illuminated-dial, direct-current ammeter. The second switch-board consists of two panels, Nos. 1 and 2, each being duplicates of corresponding panels on Switch-board No. 1. On swinging brackets at the ends of these panels there are mounted one 150-volt, illuminated-dial, direct-current, voltmeter, and one 150-ampere, illuminated-dial, direct-current ammeter.

All wiring, except high-tension wiring, is in accordance with the November, 1903, Yards and Docks Specifications of the U. S. Navy, and all wires used in connection with the control board have flame-proof covering.

Refrigerating Plant.—The Carbondale Machine Company, of Carbondale, Pa., furnished and erected a Carbondale, absorption-type, refrigerating plant in the south end of the power-plant. It has a nominal cooling capacity equal to that of 50 tons of melting ice every 24 hours. It is capable of cooling from 75° to 40° Fahr., and circulating 600 gal. of drinking water per hour; cooling 30 000 cu. ft. of refrigerator boxes in the kitchen, serving-, and lunch-rooms to 38° Fahr.; 10 250 cu. ft. of space in the mortuary chamber to 32° Fahr., and freezing 50 gal. of ice-cream.

In performing this work, the drinking water is cooled by ammonia coils, and all other refrigeration by brine coils, the plant being guaranteed to cool 200 gal. of brine from a temperature of 0° to —5° Fahr. per min.

The plant is made up of the following parts: A generator, an



TYPICAL ILLUSTRATION OF AN ABSORPTION TYPE OF REFRIGERATING PLANT

FIG. 6.

analyzer, an exchanger, a rectifier, a condenser, an atmospheric absorber, a weak-liquor cooler, an anhydrous receiver, an aqua receiver, a brine cooler, two aqua ammonia pumps, two brine pumps and two drinking-water circulating pumps.

The generator has a cast-iron shell, about 14 ft. long, with a flanged T at one end to receive the analyzer shell, and four lugs at the other end for carrying the exchanger shell. Its steam coils are of heavy lap-welded pipe with cast-steel bends.

The analyzer has a cast-iron shell, about 4 ft. long, and rests on the T-nozzle of the generator. It has cast-iron analyzer trays caulked into the analyzer shell with lead packing. The exchanger is mounted on the lugs of the generator and supported on ornamental columns. It has a cast-iron shell, about 8 ft. long, and has spiral coils of 1-in and 1¼-in. pipe.

The rectifier is of 3-in., lap-welded, extra-heavy, wrought-iron pipe submerged in a tank supported on iron standards above the generator. The condenser is of the atmospheric type, and is in four sections, each section containing 24 runs of 2-in., extra-heavy pipe. The brine cooler has a cast-iron shell, about 9 ft. long, and spiral brine coils, the inlet and outlet ends of which are connected with the brine circulating pipes.

The atmospheric absorber is in four sections, each having 15 runs of 3-in. ammonia pipe. The two aqua ammonia pumps are of the direct-acting type, and were built by the Foster Pump Works. The cylinders are 6 in. in diameter, with a stroke of 12 in. A set of four nickel-rim pressure gauges with 8-in. cases marked, respectively, generator, cooler, absorber, and steam, mounted on an ornamental iron frame with necessary shelf and brackets, and three sets of ¾-in. Ball gauge cocks with glasses for indicating the liquid level of the several parts, were supplied with this plant.

Each part of the machine was constructed to stand a test under hydraulic pressure of not less than 500 lb. per sq. in., before leaving the works, and all coils to stand an air pressure of not less than 300 lb. per sq. in. while submerged in water for the purpose of locating the leaks. The bodies of the generator, exchanger, analyzer, and cooler are covered with insulating material and finished with hardwood sectional lagging bound with nickel hoops. This apparatus is operated by city water and superheated steam at 150 lb. pressure, and to do the neces-

sary pumping and refrigeration will require not more than 2 800 lb. of superheated steam. The steam for operating the generator is obtained from the exhaust of the ammonia, brine, and drinking-water circulating pumps.

The brine is drawn from a storage tank and circulated through the brine cooler of the refrigerating machine by the brine-circulating pump. The cooled brine is discharged from the cooler coils and forced about 1 800 ft. to the brine coils in the service- and storage-rooms at the station, thence it is returned to the brine tank at the power-house to be cooled again. The brine coils in the cold-storage rooms are of 1-in. galvanized-iron pipe, and have return bends at 4½-in. centers and coils of about 100 ft. run, each coil being controlled by a valve at inlet and outlet and fitted with a ¼-in. cock for the removal of air. The main from the brine tank to the pump suction is 4 in. in diameter, that from the pump discharge to the cooler inlet is 3 in.

The brine pumps are of the duplex, double-acting, service type, built by the Deane Pump Works, with 6-in. cylinders and a 12-in. stroke. The brine-storage tank has a capacity of 3 500 gal., and is in two sections, each 15 by 3 by 6 ft. The brine is made of "Solvay" chloride of calcium, 1.225 specific gravity.

The drinking-water circulating system is arranged as follows: Water is supplied to the storage tanks under city pressure, the supply being controlled by a float-valve, and is cooled by circulating ammonia coils submerged in the tanks. From these tanks the water is circulated by pumps through the flow and return mains to the drinking fountains in the station and in the expresss building.

The water-cooling and storage tank, in two sections, each 10 by 3 by 6 ft., is in the power-house, and has a capacity of 1 500 gal. It contains 200 lin. ft. of galvanized, jointless, direct-expansion, ammonia coils, in sections, each controlled by inlet and outlet valves. The water-circulating pumps are of the double-duplex type, the pump cylinders, 4½ in. in diameter with a 12-in. stroke, are bronze-fitted on the plunger end. They were built by the Deane Pump Works.

The operation of this plant is briefly as follows: Sufficient commercial aqua ammonia to submerge the coils completely is placed in the generator shell. When heat is applied, by passing exhaust steam through the coils, the aqua ammonia gives up some of its vapor, which passes through the analyzer to the rectifier, where any water vapor

is trapped and returned through a drip line to the analyzer, from which it passes by gravity into the generator. This ammonia gas, which is hot and at a high pressure, after leaving the rectifier passes into the condenser where it is cooled to a point at which it liquefies under that pressure. The pressure in the generator, rectifier, and condenser is fixed by the temperature of the condensing water.

This liquefied anhydrous ammonia then flows into a receiver having gauge glasses for the purpose of indicating the level of the liquid. The anhydrous ammonia is then admitted into the brine cooler by an expansion valve, and there, owing to its expansion from the high pressure of the condenser to the low pressure of the cooler, it is converted to a gas. This change of state absorbs heat from the brine which is being circulated through the coils in the cooler by the brine pump.

The ammonia gas, having performed its function in the brine cooler, is now returned to the generator by the absorber, which consists of a vertical stand of pipes over the outside of which water from the condenser passes for the purpose of cooling it. The ammonia gas is drawn from the cooler into the absorber by reason of its affinity for water. In order to utilize this property, advantage is taken of the fact that, owing to the difference in specific gravities, the weakest aqua ammonia lies in the bottom of the generator. A small pipe, therefore, is led from the bottom of the generator through the coil in the exchanger, thence through the weak-liquor cooler to the absorber, where, by a spray valve, the weak ammonia liquor mixes with the gas coming from the brine cooler, absorbs it rapidly, and produces a suction action which tends to draw gas from the cooler continuously.

The mixing of the weak liquor with the strong gas from the cooler forms strong aqua ammonia, which flows from the absorber to the aqua receiver, from which it is pumped by a small direct-acting pump through the exchanger into the analyzer, from which point it flows by gravity into the generator. In this way the strength of the solution in the generator is maintained and the operation of distillation is made continuous.

The exchanger is installed in the interest of economy in steam, as follows: The hot weak liquor, in passing from the generator to the weak-liquor cooler, passes through the exchanger, where its heat is utilized in raising the temperature of the strong aqua ammonia coming

from the absorber; conversely, the cold, strong aqua ammonia assists in cooling the weak liquor on its way to the weak-liquor cooler. The colder the weak liquor the more gas it will absorb, and the warmer the strong ammonia is when reaching the generator the less heat will be required to generate the gas.

The practical working of a machine of this style is very simple. Under proper operation of the steam-pressure regulating-valve the distillation is practically uniform. The speed of the ammonia pump is controlled by a float-valve which maintains a constant level in the aqua receiver and generator. Under the above conditions the only variation is in the expansion-valve, which must be regulated to suit the temperature desired in the brine cooler. When the cooling load is fairly constant very little adjustment is necessary in any of the valves, as long as the steam pressure is unchanged.

The advantages of the absorption system are its ability to utilize exhaust steam, the possibility of obtaining lower temperatures than from compression machines of the same rated capacity, the durability of the parts, simplicity of operation, absence of noise and vibration, minimum number and low speed of moving parts, adaptability to space conditions, and safety with regard to fire insurance.

Crane.—The Niles-Bement-Pond Company, of Philadelphia, Pa., furnished and erected an overhead, three-motor, electric, traveling, 10-ton crane, in the engine-room on a runway put in in connection with the structural steel framework of the power-house, the span being 32 ft. 3 in., or approximately the width of the room.

The hoist is designed for a working load of 20 000 lb. and a test load of 25 000 lb., with a maximum lift of 36 ft. The running rigging is extra-pliable, plow-steel, wire rope. The hoist is operated by a 20-h.p. motor, and has a speed of 20 ft. per min. under full load, and 40 ft. under no load. The trolley motor is 3-h.p., with a speed of 100 ft. per min. under full load, and 125 ft. under no load. The bridge motor is 7½-h.p., and has a speed of 250 ft. per min. under full load, and 300 ft. under no load. The girders are of the box type; the motors and controllers are of the Niles type, and operate by direct current at 125 volts.

Blow-off Tanks.—At the base of the chimney there are two blow-off tanks, each 12 ft. long, 57 in. in diameter, and of ⅜-in. steel plates. The boilers are connected with these tanks by a 3-in. main, with 2½-in.

front and rear connections with each boiler. Each tank has a capacity of about 1 750 gal. There is a 6-in. connection between the tops of the tanks and the exhaust riser in the stack, and sewer connections are made with the bottom of each tank.

Oil Filters.—An oil-filtering system, consisting of two 300-gal. filters connected to one 250-gal. storage tank, three 60-gal. oil-storage tanks, one storage reservoir, 18 in. in diameter and 72 in. high, two cast-iron, galvanized sinks, and two 3 by 2 by 3-in. duplex, double-acting, steam pumps, with the necessary fittings, was furnished by the American Automatic Oil Filter Company, of Philadelphia, Pa.

Piping System.—All piping in the power-plant and between the power-plant and the station and express building, except that in the drinking-water and brine-circulating systems, was put in by W. K. Mitchell and Company, of Philadelphia, Pa. The drinking-water piping was put in by the Wells and Newton Company, of New York, and the brine piping by the Carbondale Machine Company, of Carbondale, Pa.

The arrangement of the steam piping in the power-plant is very simple. It consists essentially of a 10-in. main header extending the length of the boiler-room and in the rear of the boiler settings. The connections between the boilers and the header are made through the super-heaters by a 6-in. branch connecting the outlet of each super-heater by a long-radius bend with the top of the header.

The header is divided into ten sections, with valves and by-passes, one for each boiler unit installed, with three sections blank for future extension of boiler units. Short direct connections are made with the steam-using machinery in the engine-room through openings in the longitudinal wall between the engine- and boiler-rooms. The blow-off piping consists of 3-in. mains, with 2½-in. front and rear connections with each boiler, and a 6-in. connection between the blow-off tanks and the exhaust riser in the stack.

The water supply for the power-plant, station, express building, and train yard is received through the power-plant from two sources: A 12-in. connection with a 24-in. main on K Street, and a 12-in. emergency connection with a 12-in. main on H Street, a **T** being provided in the line opposite the southwest corner of the power-house, with the necessary valves and by-passes. From this point the supply is carried to the various tanks in the south end of the plant, to the condensing machinery, feed-water heaters, and pumps.

The circulating piping between the condensing machinery and the cooling tower consists of a 24-in. suction line and a 24-in. discharge line, the latter terminating in an 18-in. stand-pipe in the center of the tower. There is also a 3-in. cold-water connection and an 8-in. overflow between the cooling tower cistern and the power-house.

The general piping between the power-plant and the station and express building, most of which connects directly with the power-house equipment, consists of: A 2-in. drinking-water circuit to the station and a 1-in. circuit to the express building; a 3-in. brine-circulating system to the station; an 8-in. hydraulic-elevator circuit (with 4-in. branches at H Street leading to the express building and 6-in. branches at the concourse, one group leading to the baggage elevators in the south end of the train yard, the other to the elevators in the station proper); a 16-in. exhaust steam line for heating, with an 8-in. branch to the express building; a 4-in. return for condensation from the station and express building; an 8-in. steam line for car-heating and cooking (branching near H Street into a 4-in. line to the express building, a 3-in. line to the station, and a 6-in. line to the concourse, at which point a 3-in. branch is carried into the station, the 6-in. line running along the concourse for car-heating on the station tracks); an 8-in. fire line, with a 6-in. branch to the express building; a 6-in. water line, with a 3-in. branch to the express building; a 3-in. air line to the concourse, with a 3-in. branch to the express building and a 1½-in. air line for the elevator system, with a 1½-in. branch to the express building.

Rolled-steel, lap-joint flanges were used in joining all these pipes except the smaller sizes, which were put together with screw flanges. Expansion bends were used in the 4-in. steam return and in the 6-in. live-steam supply in the main tunnel. Expansion joints were used elsewhere on all steam supply and return lines.

Pipe Covering.—All the piping, except the drinking-water circuit, was covered by the Philip Carey Company, of Lockland, Ohio. On all the pipes, valves, fittings, and flanges of all high-pressure steam lines, high-pressure steam drips, exhaust lines, and return hot-water lines, 85% magnesia sectional covering was used. The thickness of the covering on all high-pressure steam lines and other lines 8 in. in diameter and greater was 1½ in.; on all lines more than 1 in. and less than 8 in. in diameter, it was 1 in.; and for lines 1 in. in diameter and less, ⅞ in.

The covering was secured by staples applied along the joints at intervals of 6 in., and bound with No. 18 galvanized-iron wire at intervals of 12 in. The joints and cracks between the sections of covering were carefully filled and pointed with magnesia cement. Over this covering was placed an 8-oz. duck jacket, securely stitched in place and finished with two coats of approved paint. The brine piping, including the valves, fittings, and flanges, has sectional, cork covering, 2½ in. thick. The sections were cemented together, bound with No. 18 galvanized-iron wire, and finished with two coats of hot asphaltum. The pressure and discharge lines for elevators, fire lines, building service, and air lines, including valves, fittings, and flanges, have sectional cork covering, 1 in. thick, cemented and bound as above, and covered with an 8-oz. canvas jacket, finished with two coats of approved paint.

The Philip Carey Company also applied covering to boiler drums, feed-water heaters, and turbine connections, lined the boiler nozzles, smoke-flues, and uptakes, and cleaned and painted pipes and miscellaneous apparatus in the plant.

Elevator System.—An elevator system, exclusive of the general piping, was put in by Morse, Williams and Company, of Philadelphia, now the Otis Elevator Company. It consists of one baggage, one freight, and two passenger elevators, and three dumb-waiters in the station, three baggage elevators in the basement under the concourse, eight baggage elevators in the train yard along the north line of the concourse, five express elevators in the express building, and one freight elevator each in the power-house and inspectors' building.

With the exception of the dumb-waiters, the entire system is of the hydraulic-plunger type, operated under a closed-tank system, with pressure at the pumps of from 300 to 320 lb. per sq. in. on the supply line and back-pressure of about 20 lb. on the return line. Discharge tanks were placed in the attic, but, owing to the fact that there are individual pressure and discharge tanks at each elevator, more satisfactory operation has been obtained without the use of the attic tanks. The dumb-waiters are operated by electric motors.

Table 2 shows the numbers by which the elevators are now designated, the letters used by the architects in designating the groups when the contract was made, the location, kind of service performed, the rise, and the number and size of tanks used on the pressure and discharge lines at each elevator. The pressure tanks as arranged have

TABLE 2.—ELEVATOR SYSTEM IN THE WASHINGTON TERMINAL.

Number.	Letter.	Location.	Service.	Rise.	Number and Size of Tanks.	
					Pressure.	Discharge.
1	A	West office entrance......Station....	Passenger.....	First to third floor............	2—2 ft. 6 in. by 10 ft. 8 in.	2—2 ft. 6 in. by 10 ft. 8 in.
2	C	Baggage checking-room.. “	Baggage.......	Basement to first floor........	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
3	B	East office entrance....... “	Passenger.....	First to third floor............	2—2 “ 6 “ “ 10 “ 8 “	2—2 “ 6 “ “ 10 “ 8 “
4	D	Service-rooms............. “	Freight........	Basement to third floor.......	2—2 “ 6 “ “ 10 “ 8 “	2—2 “ 6 “ “ 10 “ 8 “
		Serving-room.............. “	Dumb-waiter..	First to kitchen..............		
5	F	East basement............Concourse.	Baggage......	Basement to sub-basement...	1—2 ft. 6 in. by 10 ft. 8 in.	1—2 ft. 6 in. by 10 ft. 8 in.
6	E	Baggage-room............. “	“	“ “ “ ...	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
7	E	“ “ .... “	“	“ “ “ ...	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
8	H	Train yard................Low level..	Inv. and Bagg.	Concourse to sub-basement..	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
9	I	“ “ .... “ “ ..	Baggage.......	Low level to sub-basement...	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
10	I	“ “ .... “ “ ..	“	“ “ “ “ ...	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
11	I	“ “ .... “ “ ..	“	“ “ “ “ ...	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
12	I	“ “ .... “ “ ..	“	“ “ “ “ ...	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
13	G	“ “ ....High level.	“	High level to baggage-room..	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
14	G	“ “ .... “ “ .	“	“ “ “ “ “ ..	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
15	G	“ “ .... “ “ .	“	“ “ “ “ “ ..	1—2 “ 6 “ “ 10 “ 8 “	1—2 “ 6 “ “ 10 “ 8 “
16	M	Express building........................	Express........	Basement to first floor........	2—2 “ 6 “ “ 5 “ 8 “	2—2 “ 6 “ “ 5 “ 8 “
17	M	“ “	“	“ “ second floor.....	2—2 “ 6 “ “ 5 “ 8 “	2—2 “ 6 “ “ 5 “ 8 “
18	M	“ “	“	“ “ first floor........	2—2 “ 6 “ “ 5 “ 8 “	2—2 “ 6 “ “ 5 “ 8 “
19	M	“ “	“	“ “ second floor.....	2—2 “ 6 “ “ 5 “ 8 “	2—2 “ 6 “ “ 5 “ 8 “
20	M	“ “	“	“ “ “ “	2—2 “ 6 “ “ 5 “ 8 “	2—2 “ 6 “ “ 5 “ 8 “
21		Power-house............................	Freight........	“ “ attic............		
22	N	Inspectors' building....................	“	“ “ track level......		
		At pumps................................			2—4 ft. 8 in. by 13 ft. 8 in.	6—2 ft. 6 in. by 10 ft. 8 in.

capacities equal to six times the discharge of the plungers, and are filled with air and water in equal proportions.

Each passenger elevator has a lifting capacity of 3 000 lb. at a speed of 250 ft. per min., and, with a load of 1 200 lb., a speed of 350 ft. per min. can be attained. The freight elevators have a capacity of 3 500 lb. at a speed of 250 ft. per min., and a maximum lifting capacity of 5 000 lb. at a slow speed. The baggage and express lifts have a capacity of 7 000 lb. at a speed of about 50 ft. per min. Two of the dumb-waiters have a capacity of 100 lb. at a speed of 200 ft. per min., the third has a capacity of 250 lb. at a speed of 100 ft. per min.

All the cylinders are encased in $\frac{3}{8}$-in. wrought-iron casings for their entire depth, and made of standard wrought-iron pipe, with outside couplings and inside brass liners at the joints. The plungers are of heavy steel tubing, surfaced and polished in lathes. The cars of the passenger and service elevators in the station are of mahogany and ornamental iron. The floors and platforms of all elevators are of clear quarter-sawed maple.

The two passenger elevators and the service elevator in the head-house have flash-light annunciators, and are controlled by a wheel and cable-operating device. There is also a safety device which prevents the doors from being opened except by the operator in the car, and locks the controlling device when the car is at a landing with the door open, thus the car cannot leave the floor until the door is closed.

The baggage and express elevators, and the freight elevators in the power-house and inspectors' building are operated by hand cables. At each floor there are substantial iron enclosures, with gates arranged to be raised by an operating device on the lift. There are iron shields or deflectors on the under side of all floor openings. The dumb-waiters are operated by a system of push-buttons; the doors must be closed before the car leaves the floor, and cannot be opened until it arrives at the landing to which it is dispatched.

The general piping for the elevator system was furnished and put in by W. K. Mitchell and Company, of Philadelphia, Pa., and included the supply and return pipes extending from the power-house through the pipe tunnel to the station, and thence by all elevators and connecting with the pipes leading to the tanks in the attic. All elevator pipes in the station and express building are laid in concrete trenches covered with cast-iron plates.

Express Facilities.—A 60 by 450-ft. building was erected along Second Street between H and K Streets, N. E., opposite the power-house, for the Adams, Southern, and United States Express Companies. The structure is of brick and steel, with a roof of red Spanish tile, the architectural treatment and general construction being similar to that of the power-house on the opposite side of the yard. The two structures form a group of buildings of very pleasing design flanking the entrance to the train yard.

The express building consists of a basement, with underground driveways 35 ft. wide along the east and west sides and north end; a main or track-level floor, with driveway along the east side and tracks adjoining the west side and north end; a second or office floor; and an attic or storeroom. The floors of the basement and main story are of concrete, the other floors are of wood. Fire-walls divide the building into three sections, the southernmost being used by the United States Express Company, the other two by the Adams and Southern Express Companies, jointly.

The building has five hydraulic-plunger elevators, three extending from the basement to the office floor, and two from the basement to the main floor only. It is lighted by electricity, the office floor by incandescent lamps, the other floors by arc lamps. Fire protection is provided by hydrants outside and hose connections on fire-risers inside the building. There are two fire-proof vaults on each floor, including the basement, one in the section occupied by the United States Company, the other in that occupied by the Adams and Southern Companies. There are drinking fountains, connected with the general drinking-water system, in all parts of the building.

The tracks approach the building at an angle of about 13°, so as to provide more standing room for cars. They are in pairs and are separated by trucking platforms, the entire layout having a capacity of about 27 cars. The tracks and platforms are covered for some distance from the building by concrete-steel shelter sheds for facilitating the handling of express matter in inclement weather.

All work in connection with the construction of the express building, power-house, and K Street interlocking tower, except furnishing and erecting the steelwork, and putting in the electric conduits and lighting fixtures, was done by James Stewart and Company, of New York. The steelwork was furnished and erected by the American

Bridge Company, of New York, and the electrical work was done by A. S. Schulman, of Cincinnati, Ohio. These structures are more fully described elsewhere in this paper.

The umbrella sheds and platforms, to which reference is made elsewhere, and the stairways leading from the concourse to the low-level tracks, were also constructed by James Stewart and Company, who furnished all labor and material, except for the conduits and lighting fixtures, which were provided and put in by Mr. Schulman. The architectural work was executed by D. H. Burnham and Company, of Chicago.

Interlocking.

Three electro-pneumatic interlocking plants were put in by the Union Switch and Signal Company, of Pittsburg, Pa. One is between New York Avenue and Florida Avenue, on the west side of the tracks of the Metropolitan Branch of the Baltimore and Ohio Railroad, known as the New York Avenue Tower. It controls the switches and signals of the scissors-crossing at the point of convergence of the railroad lines entering the terminal from the north, and the switches and signals governing the movements of equipment between the coach and engine yard and the station. Another is at the south side of K Street, in the center of the throat of the train yard, and is known as the K Street Tower. It controls the switches and signals governing the movements in and out of the train yard. The third is immediately north of the concourse line, at the entrance to First Street Tunnel. It controls the switches and signals under Massachusetts Avenue Plaza, and is known as the Massachusetts Avenue Tower.

In addition to the interlocking plants, as above noted, there is an intercommunication system connecting with the outlying towers, and a train-starting signal system, the latter being the first of its kind to be put in service.

The New York Avenue machine has a 71-lever frame with 58 working levers; the K Street, the largest of the group, has a 191-lever frame with 162 working levers; the Massachusetts Avenue, the smallest of the three, has a 29-lever frame with 20 working levers. Out of a total of 291 lever spaces in the three machines, there are 240 active levers, leaving 51 spaces for future extensions. There are 108 working switch levers, operating 73 single switches, 5 derails, and 43 slip-switches with movable-point frogs. There are 106 working signal

levers, operating 251 three-position signals and 157 two-position signals, or a total of 408 signals. Of the working signals, 30 are light signals at the Massachusetts Avenue plant for tunnel operation. In addition to the total of 408 working signals, there are 164 fixed blades for carrying out the speed-signaling principle.

The adoption of electro-pneumatic machines with right-and-left lever operation, effected a saving of 90 signal levers over any other type of power machine, and a consequent reduction in the size of the towers. There was also a great saving of space in the yard over what could have been accomplished with any other than a straight electric plant. The pipes, racks, cranks, and other equipment of a manual machine could not have been put in to operate the large number of switches and signals in these localities without interfering seriously with the track layout.

The New York Avenue Tower is a three-story-and-basement structure, 12 ft. 10 in. wide and 31 ft. 6 in. long, with one-story extensions, 12 ft. 10 in. wide and 30 ft. long, at each end. The basement is of concrete, the first and second stories of brick, and the third of frame construction covered with sheet copper. The roof is of wood covered with Ludowici tile. The basement contains the heating apparatus, coal bins, and transformer vault. The offices, repair-room, battery-room, and toilet are on the first floor. The relays and switch-board are on the second floor. The machine, track diagram, telegraph instruments and indicators, and push-button cabinets used in connection with the intercommunication system are on the third floor.

The K Street Tower is a three-story-and-basement structure, 12 ft. 10 in. wide in the basement, first, and second stories, and 61 ft. long. The third story is 15 ft. wide and 61 ft. long. It has a one-story extension, 12 ft. 10 in. wide and 45 ft. long, at the north end, and another at the south end of the same width and 50 ft. long. The basement is of concrete, and extends the entire length of the tower, including the extensions. The first and second stories are of brick and the third story of steel framework and terra cotta covered with copper. The roof is a steel frame with book tile, cinder concrete, and red Spanish tile. The basement contains the transformer vault, battery racks, and racks for cables. The first floor is used for offices, storeroom for repair material, toilet, and room for motor-generator set. The switch-boards, relays, and the spring combination plates and rollers of the interlock-

ing machine are on the second floor. The combination plates and rollers are mounted vertically and attached to a structural steel frame provided especially for this purpose. This arrangement was found necessary on account of the large amount of selecting for the control of the home signals and electric detector circuits, and more especially the selecting for the third position of the signals.

The Massachusetts Avenue Tower is a one-story-and-basement structure, 15 ft. wide and 19 ft. long. The basement is of concrete and brick, the first story of steel frame and hollow tile covered with copper. The roof is a steel frame with book tile, concrete, and red Spanish tile.

The machines in these towers are of the Union Switch and Signal Company's standard electro-pneumatic type, with standard equipment for electric detector circuits, which, through the use of electric indication locks, prevents the switch levers from being moved out of position if the relays of any of the track circuits affecting any particular switch are opened by the presence of a train on these particular track circuits. The track circuits are arranged so as to obtain the maximum protection, both for the switch-point itself and all fouling movements, and, with this end in view, the track circuits are carried at least 100 ft. ahead of all switch-points, and in every case as far back as the fouling point. In the case of the ladder containing double slip-switches, the detector circuits were carried, with slip-switches reversed, to the circuit on the next parallel track, by a selection on the lever roller. This is done when sufficient facing-point protection cannot be obtained without locking the switches unnecessarily.

The illuminated track diagrams consist of a miniature reproduction of the entire track layout controlled from each machine, supported on iron-pipe stanchions at the backs of the machines at a convenient height for quick reading by the operators. The fronts of the diagrams are of glass painted black, except for the long slots representing the tracks, behind which there are 1-c.p., 14-volt lamps. Aluminum partitions separate the diagrams into sections representing those of the track. The lamps for lighting this diagram burn continuously except when track sections are occupied by trains, when the current is cut off automatically. The wires between the controlling relays and the lamps in the model are carried in the iron-pipe stanchions supporting the model.

FIG. 1.—WASHINGTON TERMINAL STATION: GENERAL VIEW OF THROAT OF TRAIN-YARD.

FIG. 2.—INTERIOR VIEW OF K STREET TOWER.

This design for track diagrams has some points of superiority over the mechanically-actuated track model, particularly that feature by which the locations of trains are shown in the territory covered by the diagram. The usual form of mechanical model only shows the routes set up, with no visible apparatus permitting one to follow the movements. The model in the K Street Tower is the largest ever built, being 19 ft. 6 in. long, 5 ft. 4¾ in. wide, and 9 in. thick. It contains 750 lamps, arranged to repeat 130 track sections, and is a fine example of good design and workmanship.

A system of locking has been established between the three towers described and the outlying towers at Second Street and Virginia Avenue, on the southern connection; at Rhode Island Avenue, on the Baltimore and Ohio Railroad's western connection; and at 12th Street and New York Avenue, on the Baltimore and Ohio and the Philadelphia, Baltimore, and Washington Railroad's eastern connection, by which movements opposing the established direction of traffic on tracks connecting all towers are prevented.

In designing the signal layout on the terminal property, the three-position speed system, with signals in the upper quadrant, was adopted. The upper arm in all cases controls the highest speed routes; the second or middle arm controls all routes where moderately high speed can be maintained, and the lower arm in all cases leads to routes where only low speeds are permissible. The low-speed signals, however, are provided with a special circuit, in which, by means of a push-button operated by permission of the train director, a stick relay may be thrown in series with the magnet of the low-speed arm, clearing the latter for the different routes which may be occupied. All signals assume automatically the clear 90° position from the next high-speed signal ahead over the route set up, providing the signal in advance is in the caution 45° or clear 90° position.

The signals are supported on 18 signal bridges, 9 of which were furnished by the American Bridge Company, of New York, 5 by the Toledo-Massillon Bridge Company, of Massillon, Ohio, and 4 by Barber and Ross, of Washington, D. C. The bridges range in length from 33 to 145 ft., and all but those furnished by Barber and Ross are supported on steel bents anchored to concrete foundations. Those furnished by Barber and Ross are supported on the tops of the um-

brella sheds near the north entrance to the First Street Tunnel, and carry signals controlling movements into the tunnel.

Each tower is provided with duplicate groups of batteries of such number of cells as to meet the requirements; these are either in the battery-room in the tower or in boxes or cupboards in the bents of the signal bridges, distributed as shown in Table 3.

TABLE 3.—STORAGE BATTERIES FOR INTERLOCKING PLANT.

Tower.	Number of cells.	Where placed.
New York Avenue, or "C" Tower.	70	Battery-room, "C" Tower.
	10	Box, west end, Signal Bridge "K."
	8	Box, east end, Signal Bridge "M."
	4	Box, west end, Signal Bridge "L."
	4	Automatic signals, Metropolitan Branch.
K Street, or "K" Tower..........	112	Battery-room, "K" Tower.
	8	Box, east end, Signal Bridge "E."
	8	Box, west end, Signal Bridge "E."
	12	Box, west end, Signal Bridge "H."
Massachusetts Avenue, or "A" Tower..........................	158	Battery-room, "A" Tower, in middle wall.
	6	Box No. 1, First Street Tunnel.
	2	Box at Signal No. 1366, First Street Tunnel.

Eighty ampere-hour storage batteries of the chloride accumulator type, furnished by the Electric Storage Battery Company, of Philadelphia, Pa., are used for energizing the track circuits, indicators, relays, and electric locks.

The batteries are in duplicate in order to permit the charging of one half while the other half is discharging, without influencing the discharging side. All cells are grouped and located at each point so as to operate the various functions for a period of 4 days as a minimum from one charging. For charging, the batteries are connected in series, and for discharging, in parallel. This operation is effected by special switches.

All the 2-volt track batteries discharge in multiple, but in the interlocking batteries, where from 12 to 14 volts are used customarily, the cells are arranged for discharge in groups of seven cells each, in series, and a sufficient number of these series are grouped in parallel to last the required 4 days. The batteries are charged from K Street Tower, where the motor-generator set is located. There are 263 track circuits in the layout, representing the equivalent of 18 miles of single track, and all are fed from storage batteries at 2 volts.

There are 734 relays in the entire layout, 263 of which are track relays. All are enclosed in suitable cupboards and cases. Those

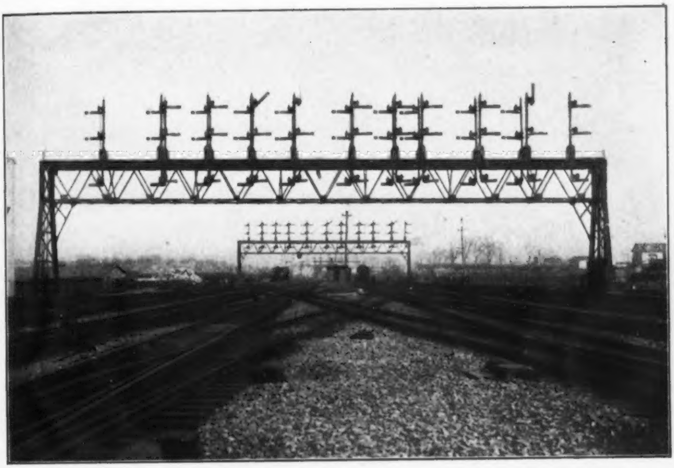


FIG. 1.—WASHINGTON TERMINAL STATION: SIGNAL BRIDGE AT DIAMOND CROSSING.

FIG. 2.—GENERAL VIEW OF NORTH APPROACH TO STATION.

scattered over the yard are housed in cupboards built in the bents of the signal bridges. In the towers the relays are enclosed in a combined rack and terminal board, suggested by the Signal Company, but built by the Terminal Company, in which all relays and wires are readily accessible. Flexible electric-light cord is used between the binding posts on the relays and those on the terminal board, so that the relays can be handled and inspected without disturbing the connections. The relays are distributed as shown in Table 4.

TABLE 4.—NUMBER OF RELAYS IN INTERLOCKING PLANT, AND THEIR DISTRIBUTION.

Tower.	Number of relays.	Capacity.	Where placed.
New York Avenue, or "C" Tower.	9	12-ohm	Box, west end, Signal Bridge "K."
	17	12-ohm	Box, west end, Signal Bridge "L."
	5	12-ohm	Box, west end, Signal Bridge "N."
	2	12-ohm	Signal No. 52-L, Washington Branch, P. R. R.
	2	12-ohm	Signal No. 60-L, Metropolitan Branch, B. & O. R. R.
	2	12-ohm	Automatic Signals, Metropolitan Branch.
	2	12-ohm	Signal Bridge "R," Washington Branch.
	12	12-ohm	Relay-room, "C" Tower.
	26	150-ohm	" " " "
	62	1 000-ohm	" " " "
K Street, or "K" Tower.	4	12-ohm	Box, east end, Signal Bridge "A."
	4	12-ohm	Box, east end, Signal Bridge "B."
	12	12-ohm	Box, center of Signal Bridge "C."
	13	12-ohm	Box, center of Signal Bridge "D."
	13	12-ohm	Box, east end, Signal Bridge "E."
	11	12-ohm	Box, west end, Signal Bridge "E."
	8	12-ohm	Box, east end, Signal Bridge "F."
	11	12-ohm	Box, west end, Signal Bridge "G."
	25	12-ohm	Box, east end, Signal Bridge "H."
	23	12-ohm	Box, west end, Signal Bridge "J."
	8	12-ohm	Box, between "K" Tower and Bridge "H," 38 and 40 tracks.
	8	12-ohm	Box, between Bridges "H" and "J," 38 and 39 tracks.
	34	12-ohm	Relay-room, "K" Tower.
	55	150-ohm	" " " "
	157	1 000-ohm	" " " " (4-point).
	31	1 000-ohm	" " " " (2-point, high voltage).
Massachusetts Avenue, or "A" Tower.	12	12-ohm	Relay-room, "A" Tower
	12	150-ohm	" " " "
	30	1 000-ohm	" " " "
	29	1 000-ohm	Battery-room, "A" Tower.
	14	12-ohm	Relay-box, First Street Tunnel.
	46	1 000-ohm	" " " " "

The signals are lighted by electricity, one 2-c.p., 110-volt lamp being used for each signal. The lights on each side of each interlocking are controlled by a fused knife-switch on the switch-board in each tower. There is also a fused knife-switch at each signal bridge. The branch wires leading up the signal poles are encased in loricated

pipe. Cast-iron junction boxes, containing binding posts mounted on slate slabs, are used at the junctions of the loricated pipes.

The mechanism for operating the three-position signals consists of two vertical cylinders, the compressed air being admitted and released by the standard electro-pneumatic magnet and valve. Each cylinder operates a rack in a suitable guide, the racks in each pair of cylinders facing each other. Between the two racks there is a floating pinion, to which the rod for operating the blade is attached. This method of operating the three-position upper-quadrant signals was first applied on this work, and is a marked improvement in the mechanism for controlling signals of this style.

The intercommunication system of push-buttons and semaphore indicators in the towers and wire connections between them is for the purpose of announcing the movements of trains by push-buttons. This system, in addition to announcing the movements, gives information as to the class, destination, and routing of trains and equipment, and facilitates prompt disposition after they have been announced. The system is much quicker than telephone or telegraph, and equally sure. The apparatus consists of 272 semaphore indicators, 288 push-buttons, and 29 train describers. The wire used in the system is a standard, lead-covered, telephone cable, containing 160 No. 19 B. & S. gauge wires.

The train-starting system, providing for communication between train conductors, gatemen at the concourse, and tower directors, is quite novel. It is the first of its kind to be installed, and consists of light signals controlled by the above employees. At intervals of 180 ft. along each platform, in the columns supporting the train shed, there are light boxes consisting of two separate lenses behind which there are electric lamps normally dark, and a circuit controller operated by a key similar to a latch key. This method of control instead of a push-button device was adopted in order to prevent unauthorized persons from tampering with the system. At each platform gate there are two lamps, normally dark, enclosed by opalescent globes, and supported on brackets attached to the gate post opposite that in front of which the gateman stands while examining tickets and directing passengers to the trains. In K Street and Massachusetts Avenue towers there are aluminum cabinets each containing three lamps, normally dark, for each track over which each tower exercises control. The cabinet in K


West Terminal Line
East Terminal Line
STATION
CONCOURSE
Center Line of Terminal Improvement and Delaware Ave.
Dividing Wall
Straight Track to Converge
Straight Track to Converge To All Routes
To All Routes
Inspectors
Signal Bridge
Mail
End of Train Shed
CALIFORNIA AVE.
F ST.
G ST.
H ST.
Gate and Platform Indicator
Tower Light
Gate Light
Key Switch
NOTE:
Functions of platform and gate indicators
A—One minute before train is ready to leave conductor notifies tower by turning switch
B—Tower responds by lighting tower lights in gate and platform indicators.
C—Gateman notifies conductor gate is closed by turning switch and lighting gate lights in gate, platform and tower indicators.
D—Two lights displayed is authority for train to leave shed and proceed to interlocking signals.
E—Tower extinguishes all lights.
Location of Northbound and Southbound gate and platform indicators in shed are marked thus ‡ Northbound ○ Southbound.

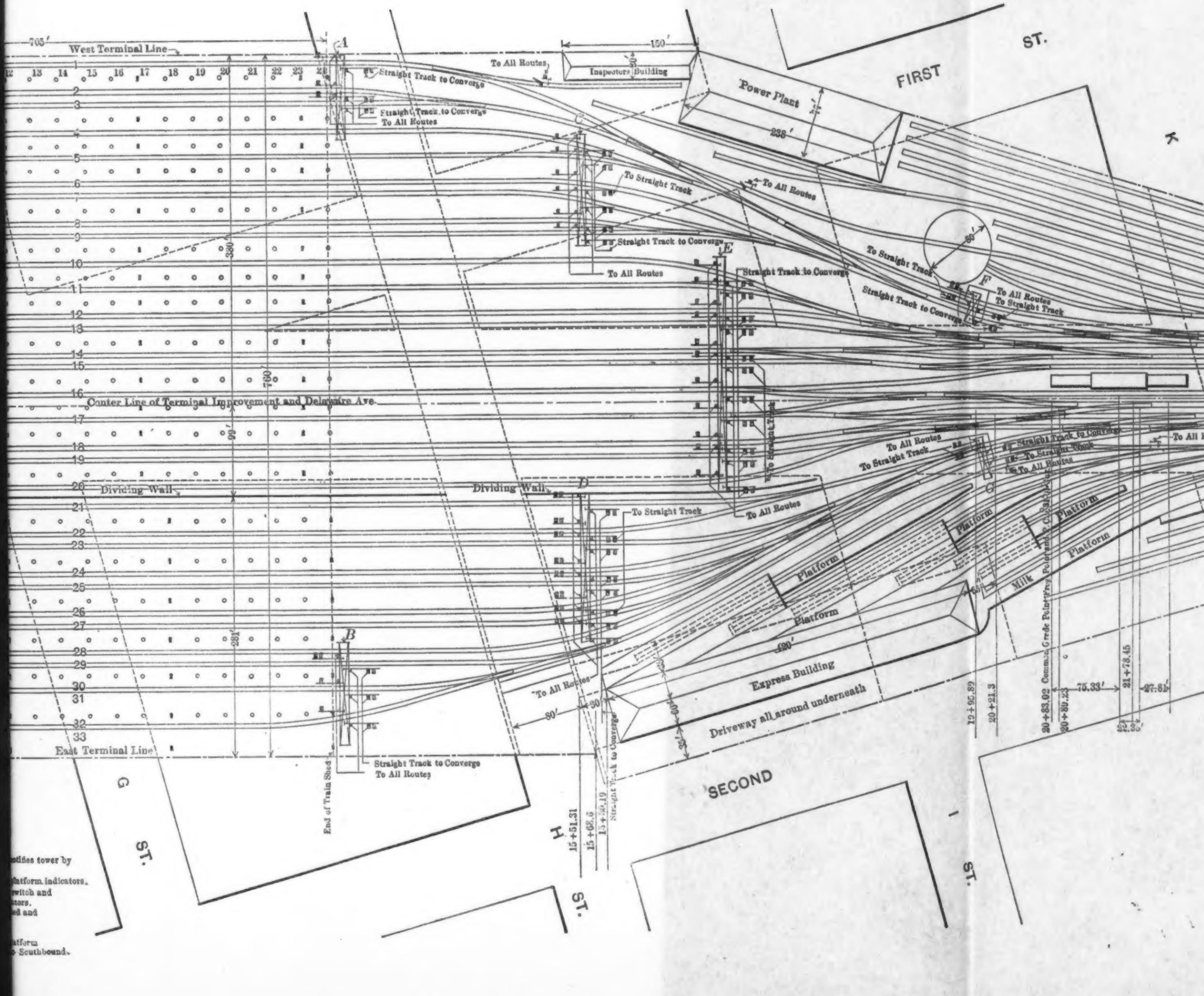

West Terminal Line
East Terminal Line
Center Line of Terminal Improvement and Delaware Ave.
Dividing Wall
Inspectors Building
Power Plant
Express Building
Driveway all around underneath
Platform
Milk
Straight Track to Converge
To All Routes
To Straight Track
End of Train Shed
FIRST
ST.
SECOND
G
H
I
K
150′
238′
420′
330
760
281
99′
80′
75.33′
15+51.31
15+68.6
19+92.89
20+21.3
20+83.02
20+89.23
21+78.45
Common Grade Point
ifies tower by
platform indicators,
witch and
tors,
ed and
latform
Southbound.

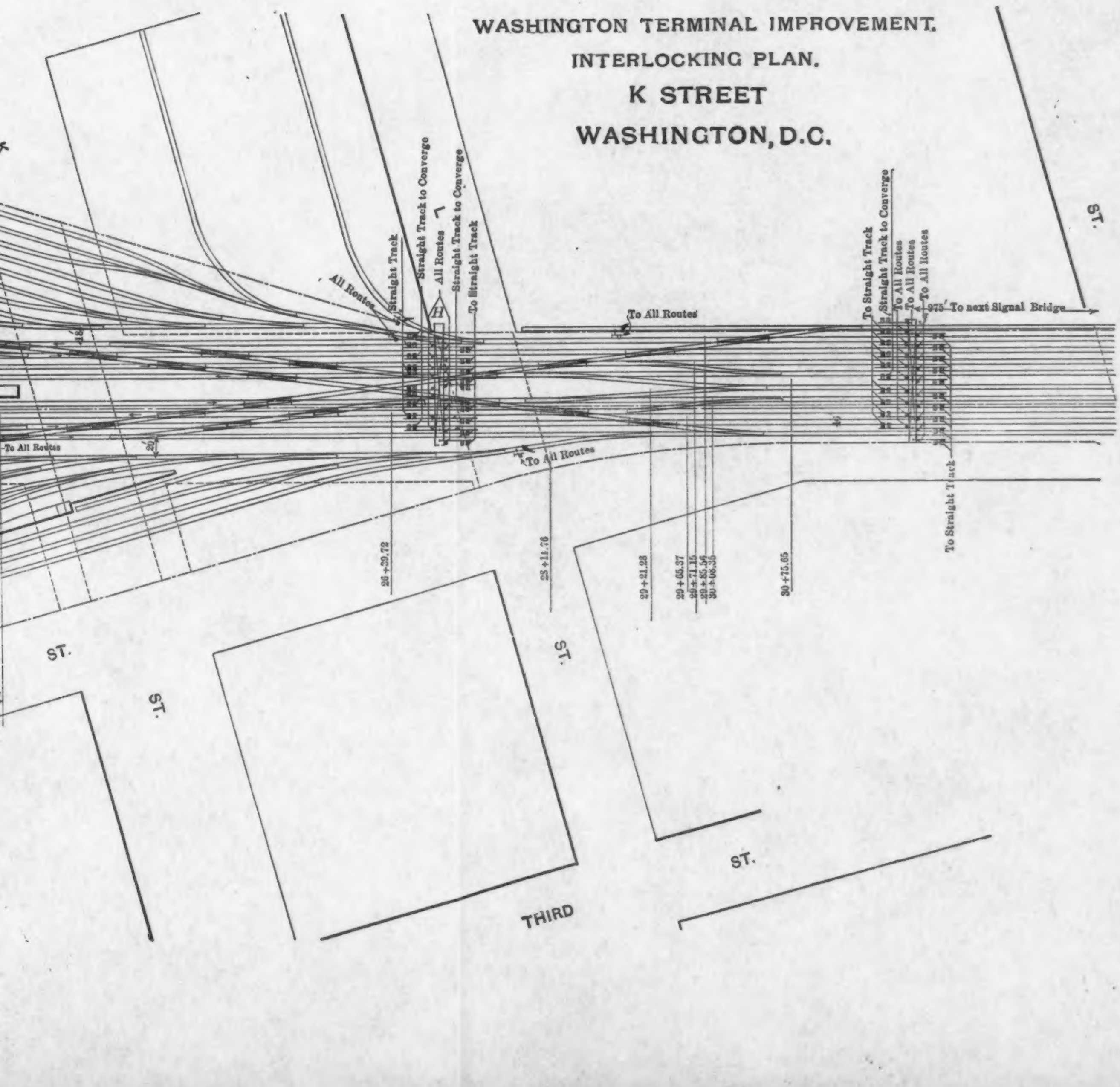
PLATE XII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXI, No. 1180.
STROUSE ON
THE WASHINGTON TERMINAL STATION.

WASHINGTON TERMINAL IMPROVEMENT.

INTERLOCKING PLAN.

K STREET

WASHINGTON, D.C.



Street tower contains 33 sets, or a set for each track in the train yard; the cabinet at Massachusetts Avenue tower has 9, for controlling the movements on the nine low-level tracks connecting with the tunnel.

About one minute before his train is due to leave, the conductor inserts his key in the bottom of the light box facing the track upon which his train stands and operates the circuit controller, lighting one of the three lights in the cabinet in the tower. The train director arranges the route and when ready presses a button in the cabinet, extinguishing the light therein and at the same time lighting another light in the cabinet and one in each of the columns and one at the concourse gate. When the time arrives for the departure of the train, the gateman closes the gate and operates a switch in a cabinet near by, which lights a second light in the columns and at the gate, and the third light in the tower. This gives the conductor the signal to move his train out of the shed to the interlocking signals, from which point the movements are governed in the usual manner. After the train leaves the shed, the lights are extinguished by the train director.

The compressed air for the operation of the switches and signals throughout the system is furnished by the Nordberg compressors in the power-house at First and I Streets, N. E. It is conveyed to the different functions through 2-in. galvanized-iron pipe at a pressure of from 80 to 90 lb., the complete system embracing two lines of 2-in. pipe extending from Massachusetts Avenue to New York Avenue. Connections between the two lines are made by carrying the cross-connections over the bridges. With a proper system of valves, it is possible to operate the entire layout from one line, leaving the other line accessible for repairs. Normally, however, both lines are in service. Before going into the system, the air is passed through an atmospheric after-cooler near the power-house; this cools and dries the air, in order that moisture may not freeze in the valves. The current for charging storage batteries and lighting signals is also obtained from the power-house, where it is generated by the Westinghouse-Parsons turbo-generators.

This signal scheme is the result of the combined ideas of the Signal Departments of the Baltimore and Ohio and the Pennsylvania Railroads; the principles carried out embody the best of each, the standards being those in use on both roads.

In this layout 3 000 000 ft. of insulated copper wire and 23 000 ft. of 2-in. galvanized-iron pipe were used, or the equivalent of nearly 570 miles of single conductor and 4⅓ miles of iron pipe.

The track arrangement covered by the New York Avenue interlocking plant consists of four double-track main lines, two operated by the Baltimore and Ohio Railroad, one by the Philadelphia, Baltimore, and Washington Railroad, and one by the Washington Terminal Company as equipment tracks between the station and the shops, together with two switching tracks, one on each side of the eight tracks above mentioned. The layout comprises 14 double slip-switches with movable-point frogs, and 7 single switches.

The K Street plant, at the throat of the train yard, controls the switches and signals of the track layout, permitting movements from the extreme east or west approach tracks to the opposite extreme tracks in the train yard. Normally, eight in or out movements can be made simultaneously to the high-level tracks and two to the low-level. This plant operates 27 double slip-switches with movable-point frogs, 58 single switches, and 3 derails, with the corresponding signals.

The track arrangement at Massachusetts Avenue is quite simple. At this point nine tracks merge into two tracks leading south through the twin tunnel under Capitol Hill to a connection with the main tracks of the Philadelphia, Baltimore, and Washington Railroad on Virginia Avenue. This is accomplished by the use of two double slip-switches with movable-point frogs, seven single switches, and one fixed crossing, the latter permitting movements to the extreme sides of the train yards from either tunnel track.

The points of special interest in this interlocking layout are the use of the three-position speed signals, involving the upper-quadrant principle of operation; the use of electric detector circuits for locking the switch levers, in lieu of detector bars; the illuminated track diagrams; the intercommunication system; the train-starting signal system; and the use of electricity for lighting the signals.

The Union Switch and Signal Company originated the upper-quadrant principle and the electric detector circuits, the first use of the former antedating the installation at Washington by about two years, the latter by a somewhat longer period.

The plants, as now completed and in service, are, no doubt, the most complete of any built to date, and are certainly a credit to the company which put them in.

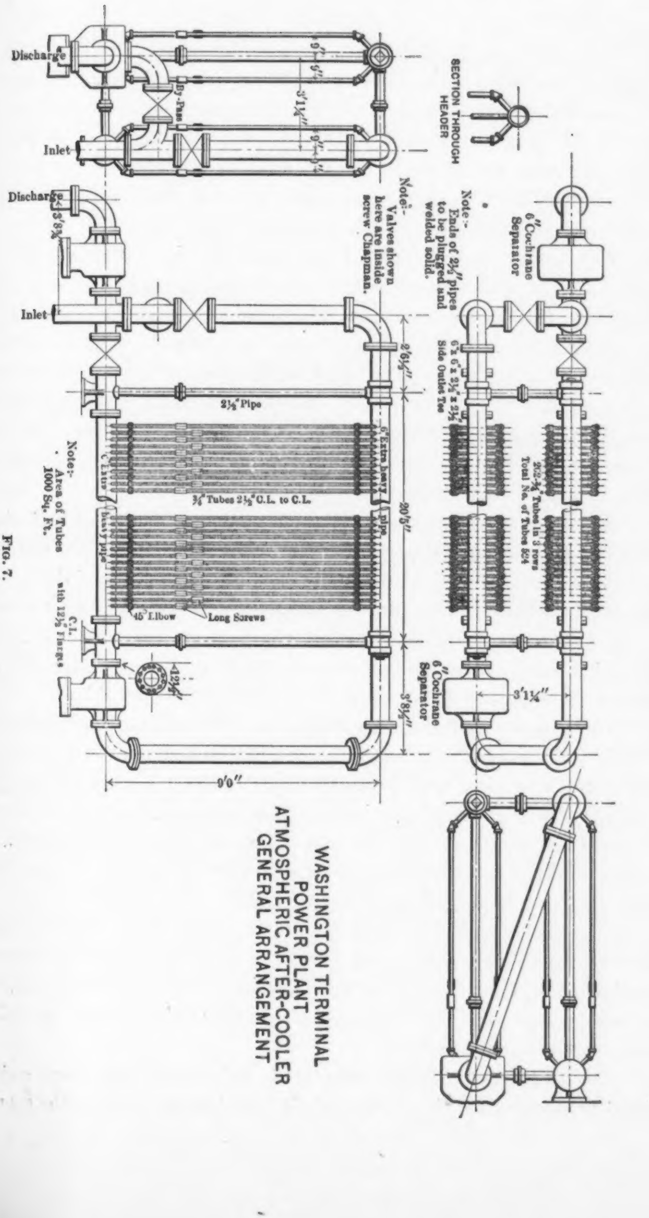

WASHINGTON TERMINAL
POWER PLANT
ATMOSPHERIC AFTER-COOLER
GENERAL ARRANGEMENT
SECTION THROUGH HEADER
Discharge
Inlet
By-Pass
Discharge
Inlet
Note:- Ends of 2½" pipes to be plugged and welded solid.
6" Cochrane Separator
Note:- Valves shown here are inside screw Chapman.
2½" Pipe
¾" Tubes 2½" C.L. to C.L.
Note:- Area of Tubes 1000 Sq. Ft.
45° Elbow
Long Screws
6" Cochrane Separator
Side Outlet Tee
9'0"
20'5"
3'1¼"

FIG. 7.

Joint Coach Yard.

The joint coach yard has a capacity of about 750 cars, and is divided into two groups known as the east and west sections. In the west section of the yard there are concrete platforms, 5 ft. wide, in the spaces between the tracks, for the use of the cleaners. The tops of the platforms are at the same elevation as the tops of the rails of adjacent tracks, thus permitting trucking across the tracks at frequent intervals, at which points there are plank crossings.

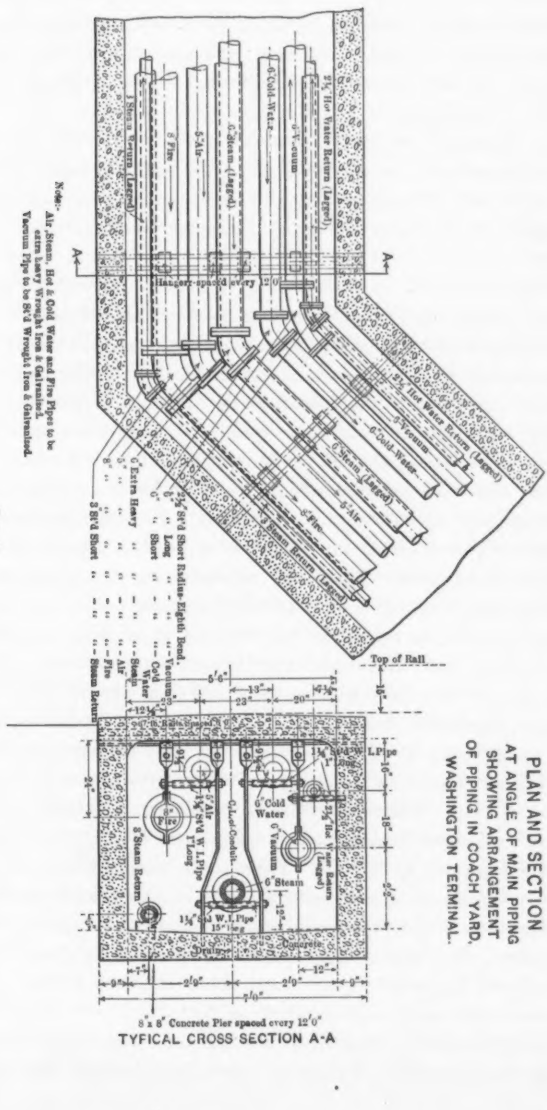
This section of the yard has a complete piping system, comprising hot and cold water, steam supply and return, air, and vacuum. The pipes are laid in concrete ducts which cross the yard, at right angles to the general direction of the tracks, at intervals of about 140 ft. Extending north and south from the power-house are reinforced concrete ducts, 5 ft. 6 in. wide and 5 ft. high, in which are the mains to which the cross-pipes are attached. No piping or platform work has been done in the east section of the yard, as it will only be used in emergencies for the storage of equipment.

A portion of the west section of the yard has been piped and wired for charging storage batteries on cars while standing on the cleaning tracks, and provision has been made for future extension of the system to other portions of the yard when needed. It has also been provided with a cleaners' building, a battery-charging station, an oil house, a kindling-wood bin, a charcoal storage building, three bedding sheds, a carpet-cleaning shed, and a power-plant along the east side.

The cleaners' building is a four-story steel and masonry structure, 50 ft. wide and 200 ft. long, with a 10-ft. cement platform along its east and west sides and its south end. It has two standard electric freight elevators, with platforms 8 ft. square, which travel from the first to the fourth floor, a distance of about 37 ft. The capacity of these elevators is 5 000 lb. at a speed of 60 ft. per min. They are operated by 110-volt, direct-current motors.

The battery-charging station is a 40 by 96-ft. brick building, with concrete and composition roof. It is divided into a generator-room and a battery-room. The former is equipped with three 50-kw. motor-generator sets, with switch-boards; the latter with the necessary racks, etc., for caring for batteries.

The oil house is a 20 by 50-ft. brick and concrete structure, and is used principally for the storage of oil used by the cleaners, the supply



PLAN AND SECTION
AT ANGLE OF MAIN PIPING
SHOWING ARRANGEMENT
OF PIPING IN COACH YARD.
WASHINGTON TERMINAL.

FIG. 8.

being obtained as needed from the main oil house at the shops. In the charcoal storage building, a 20 by 32-ft. brick structure, is stored the charcoal to be used on private and dining cars, etc. Kindling wood, for the use of private and dining cars, etc., is stored in an 8 by 60-ft. frame bin.

The bedding sheds, 300 ft. long and about 13 ft. wide, are between the tracks, spaced at 25-ft. centers, on the extreme west side of the yard. The carpet-cleaning shed, 25 ft. wide and 62 ft. long, is on the north side of T Street bridge, immediately north of the cleaners' building.

A power-plant, 65 by 96 ft., occupies a space between the east and west sections of the yard. It comprises boiler- and engine-rooms, and was designed and equipped to furnish steam heat, hot water, air for testing brakes on cars, hydraulic pressure for fire protection, and power for operating a vacuum cleaning system. It has five 250-h.p. Babcock and Wilcox water-tube boilers, arranged for grouping in batteries of two each, the above equipment forming two and one-half batteries; the walls and foundations are built for one additional boiler, to complete the other battery when needed. These boilers have a total heating surface of 13 330 sq. ft., or about 2 660 sq. ft. to each boiler, and have Roney stokers, and the necessary engine, gears, etc., furnished by the Westinghouse Machine Company. Each stoker has a grate area of 51.3 sq. ft., approximately 1 sq. ft. of grate area for every 50 ft. of boiler heating surface, and ⅕ sq. ft. for each horse power.

In connection with the Babcock and Wilcox boilers, there are five Patterson, graduated scale-beam, hydraulic, damper regulators, carrying steam pressure up to 150 lb. and having rigid connections with one main damper, to control the draft and steam pressure.

The Warren Webster Company furnished a Webster, "Starr," vacuum, feed-water heater, guaranteed to heat 50 000 lb. of feed-water per hour from 40° to 200-210° Fahr. when supplied with the proper amount of steam at atmospheric pressure. This heater consists of a cast-iron receptacle in which cold water and exhaust steam are brought into contact. It is sealed against the admission of air (hence the term vacuum) and has twelve perforated copper trays, each 13½ by 46 in., or a total tray surface of about 50 sq. ft.

The cold water is admitted at the highest point of the heater shell through an automatic regulating valve, and passes into a sealed

trough with extended lip, from which it flows in an even sheet on the perforated trays. From this point, after passing from tray to tray, it falls to a settling chamber, where a uniform level is maintained by a copper sink-pan or float. In passing through the filter the impurities fall by gravity to the bottom, while the hot water passes through the hot-water outlet chamber from which it flows to the boiler-feed pump.

The diameter of the steam inlet is 12 in.; cold-water inlet, 2½ in.; hot-water outlet, 6 in.; overflow outlet, 4 in.; and drain, 2½ in. The overflow carries off automatically any excess water, and the impurities are withdrawn through a quick-opening drain valve.

The Ingersoll-Rand Company furnished and erected a cross-compound, Corliss, engine-driven compressor, having a capacity of 1 000 cu. ft. of free air per min. The steam cylinders are 14 and 24 in. in diameter; the air cylinders are 12 and 21 in. in diameter, with a common stroke of 30 in. It is designed to operate at 85 rev. per min. under a steam pressure of 150 lb. per sq. in. against a pressure of 120 lb. When operating under these conditions the steam consumption should not exceed 20 lb. per i.h.p. per hour. The inter-cooler is of the horizontal, steel-body type. It is composed of galvanized-iron tubes through which water passes and presents a cooling surface of 300 sq. ft. to the air which circulates about them. Cross baffle-plates are placed so as to bring the air in contact with the cooling surface repeatedly, the surface being sufficient to reduce the temperature of the air to within 10° or 15° of the temperature of the cooling water.

The Laidlaw-Dunn-Gordon Company furnished a cross-compound, two-stage, Corliss, engine-driven compressor, having a capacity of 1 000 cu. ft. of air per min. The steam cylinders are 14 and 25 in. in diameter, the air cylinders 13 and 23 in., with a common stroke of 24 in. The diameter of the steam-supply connection is 3½ in., and the exhaust 7 in. The diameter of the air-suction connection is 7 in., and the discharge 4 in. It is designed to operate with a steam pressure of 150 lb., non-condensing, at a speed of 88 rev. per min., against a pressure of 120 lb. This compressor has an overhead inter-cooler of the three-pass, counter-current type, admitting air to the cooler shell through the port running around the cooler at the top of the shell, the air traversing the entire length of the cooler three times and discharging at the bottom. It has 234 ⅝-in. brass tubes, divided off by two horizontal baffle-plates. The tubes are 8 ft. 2½ in. long, and

present a cooling surface of 300 sq. ft. When operating under normal conditions the steam consumption is guaranteed not to exceed 21 lb. per i.h.p. per hour.

The M. W. Kellogg Company, of New York, built the chimney for this power-house. It has a height of 150 ft. above the foundation, an inside diameter of 8 ft. 4 in., and a flue opening 4 ft. 11 in. wide and 11 ft. high. It is circular in cross-section from foundation to top, and divided into nine sections, eight of 16 ft. 6 in. and one of 18 ft. It is constructed of improved, perforated, radial blocks with corrugated sides, and made of hard-burned refractory clay.

The blocks were laid up in mortar consisting of 1 part Portland cement, 2 parts fresh-burned lump lime and 4 parts clean sharp sand. In preparing the mortar the sand and lime paste were mixed in the usual manner; the cement was then added in small quantities as the mortar was required. The foundation was constructed by the building contractor.

The stack is lined with 4-in. fire-brick to a height of 68 ft., the lining being divided into sections supported on corbels formed in the chimney walls. It is separated from the main brickwork by a 2-in. air space. The clean-out door, 2 ft. wide and 3 ft. high, is hinged to a cast-iron frame, built into and secured to the brickwork, in the base of the chimney. At intervals of about 18 in. on both the inside and outside of the stack, there are ⅝-in., round, galvanized-iron step-irons which form a ladder extending from a point about 3 ft. above the foundation to the top.

The chimney is guaranteed to withstand a wind pressure of 50 lb. per sq. ft., and the action of gases and heat from combustion of 800° Fahr., for a period of five years from the date of completion. It is protected against lightning by an Ajax lightning conductor.

The Vacuum Cleaner Company, of New York, installed a cleaning system consisting of two 10 by 24 by 18-in. single, fork-frame, horizontal, steam-driven, vacuum pumps, built by the Clayton Air Compressor Company, designed to operate at 120 rev. per min., each having a displacement of 1 133 cu. ft. of air per min. The steam consumption is guaranteed not to exceed 30 lb. per i.h.p. per hour, with a steam pressure of 150 lb.

The pumps are connected so that one or both can be operated, as conditions require. Two separators, each 84 by 42 in., were furnished,

one dry, the other wet. The plant is designed to operate twenty 12-in. renovators at one time. To make the plant available for cleaning coaches, there is a system of piping, with necessary connections, over the entire west half of the yard. All pipe is of heavy, galvanized, wrought-iron, with galvanized, cast-iron, recessed, long-sweep elbows, T's, and Y's. The sizes of the main-line pipe are 2, 3, 4, 5, 6, and 8 in., with branches 2, 3, and 4 in. The main pipes have plugged outlets for future extension to the east portion of the yard. The main line has three cut-off valves, so as to permit repairing certain portions of the line without cutting out the entire system. The equipment also contains 2 000 ft. of Voorhees, non-collapsible hose, in 50-ft. lengths, 20 1 by 12-in. carpet renovators, 10 1 by 8-in. bare-floor renovators, 20 1 by 8-in. wall brushes, 20 1 by 6-in. cushion renovators, 20 1 by 4-in. hand renovators for curtains and car seats, 20 1 by 4-in. round-brush renovators, and 10 sets of extension tubes with observation glasses.

Two 12 by $7\frac{1}{4}$ by 12-in. boiler feed-pumps were furnished by the Platt Iron Works; two 10 by 6 by 10-in. circulating pumps and two 16 by 9 by 12-in., underwriter, 750-gal., fire pumps were furnished by the Blake and Knowles Steam Pump Works, and, for use in connection with the hot-water supply in the coach yard, the Chesapeake Machine Company furnished two tanks, 6 by $23\frac{1}{2}$ ft., each having a capacity of about 5 000 gal.

Joint Engine Yard.

The shop and engine yard is east of the coach yard, and consists of engine-storage tracks, car-repair tracks with drop-pit facilities, coal and ashes storage tracks, and the tracks used in connection with the cinder and inspection pits, the coaling station and sand-house, and the roundhouses.

The shop buildings and facilities consist of two 25-stall roundhouses, a car-repair shop, a machine and blacksmith shop, a storehouse, a power-house, an enginemen's building, an oil-house, two ash-pits, two locomotive-pits, two steel water-tanks, a coaling station, a sand-house, drop-pits in the repair yard, casting platforms and sheds, and a telpherage system at the west end of the machine and car-repair shops for handling heavy castings.

The roundhouses are brick buildings with slag roofs, 94 ft. 3 in. between the inner and outer walls, each stall being 14 ft. $3\frac{1}{4}$ in. wide at the inner and 26 ft. $1\frac{1}{2}$ in. wide at the outer end. There are engine-

pits in every stall, and drop-pits in certain stalls of the north house. The buildings are heated by steam, large radiators being placed against the outer wall of each stall. The entrances to the stalls have Wilson, wood-slat, rolling doors, and the outer walls contain large windows, furnishing ample light.

The car-repair shop is a 66 by 146-ft. brick building, with a slag roof supported on steel trusses. Skylights in the roof provide ample light. The floor space is divided into three rooms, one used as a lavatory and locker room, the other two as car-repair and wheel and axle machine shops.

The machine and blacksmith shop is an 80 by 145-ft. brick structure, with a slag roof. It is divided into two sections, one used as a blacksmith shop, the other as a machine shop. The machine shop is divided into three bays by the two lines of columns which support the roof, and a runway for a traveling crane. There is a small office and tool-room in one corner.

The storehouse, 66 by 115 ft., has a 20-ft. platform along the north side. The exterior walls are of brick, and the roof is of reinforced concrete supported on steel columns encased in concrete. This construction was adopted in order to make the structure fire-proof. There is a storekeeper's office in one corner; the remainder of the room is filled with racks and shelving for the storage of supplies.

The power-house is a 41 by 117-ft. brick building, divided into three sections. The west section contains the boilers, boiler feed-pumps, feed-water heater, and the vacuum pump on the heating system. The middle section contains the air compressor, boiler wash-out pump, two fire-pumps, and one after-cooler. The east section is used as an electric sub-station, and contains three static transformers and three motor-generator sets, with the necessary switch-boards, etc.

An 80 by 130-ft. casting platform occupies the space between the blacksmith shop and the storehouse. There is a small frame structure on this platform, in which bar and sheet iron are stored. The remainder of the area with its contents is exposed to the elements.

The enginemen's building is a 60 by 116-ft., two-story, brick structure, with Ludowici tile roof. The first floor contains offices, a lounging-room, mess-room, locker-room, lavatory, and toilet-room. The second floor contains the master mechanic's office, and sleeping apartments for the engine crews. Accommodations are provided for about 50 men.

The oil-house is a 30 by 88-ft. brick and reinforced concrete building of fire-proof construction, and consists of a main floor and basement. The oil-storage tanks are in the basement, from which there are pipes to the main floor, where they are connected with a system of measuring pumps. The entire equipment was furnished and put in by S. F. Bowser and Company, of Fort Wayne, Ind.

There are two double-track ash-pits, 156 ft. long, of the depressed type, one on either side of the approach to the coal wharf and sand-house. The engine tracks are at 24-ft. centers, and are supported on reinforced concrete foundations and walls arranged so as to provide space for the depressed track. Each pit can accommodate four engines. The engine tracks are level throughout the yard. The cinder tracks leading to the bottom of the pits are on a 5% grade.

Each ash-pit has its double-track locomotive inspection pits of concrete. Each pit can accommodate two engines, the two pits forming a group connected by a subway beneath the tracks. Entrance to the pits is effected by a stairway between the tracks, thus eliminating the element of danger to inspectors. These pits are connected with the foreman's office by a pneumatic tube system put in by the Miles Pneumatic Tube Company.

The coaling station, including the approach, is of steel; the sand-house is of steel frame and reinforced concrete. The coal wharf proper is double-track, 161 ft. long, and has storage pockets with measuring devices operated by compressed air. The approach is single-track on a 5% grade.

The sand-house is a double-track structure, 75 ft. long. Wet sand is stored in the space at each end, the drying-room is in the center. The dry-sand pockets are at the top of the structure on each side. The drying-room has four sand stoves, and pneumatic facilities for storing sand in the dry-sand pockets. The reinforced concrete roofs over the drying-room and the dry-sand pockets were water-proofed by plastering them with a mortar containing Medusa Compound, and up to the present time good results have been obtained.

The water tanks are 24 ft. in diameter and 50 ft. high, each tank having a capacity of about 160 000 gal. They receive their supply from the 12-in. main in the yard by 10-in. connections. The discharge outlets are 12 in. in diameter, and connect with a 16-in. main leading to the penstocks near the coaling station. To provide for contingencies,

a direct connection has been made between the city supply and the 16-in. penstock main. Owing to the high pressure in the city mains, this connection will only be used in emergency.

The equipment in the power-plant was designed to supply steam heat in the shop buildings, compressed air in the roundhouses, repair yard, and at the coal pockets, fire protection for the shops and repair yard, and for transforming the electric current supplied by the main power-plant to suit the voltage of the several machines in the shops operated electrically.

The Babcock and Wilcox Company furnished and erected three 250-h.p., water-tube boilers, arranged for grouping in batteries of two each, the above equipment forming one and one-half batteries, with foundations and walls arranged for an additional boiler to complete the second battery when needed. Each has a heating surface of about 2 660 sq. ft., a grate area of 51.3 sq. ft., and has Roney stokers. The complete stoker equipment was furnished and erected by the Westinghouse Machine Company.

The George A. Blake Manufacturing Company furnished two 10 by 6 by 10-in., duplex, outside, end-packed plunger, pressure-pattern, boiler-feed pumps. Two 16 by 9 by 12-in., 750-gal., standard, underwriter, fire pumps, and one 12 by 10 by 12-in. duplex, piston-packed, brass-lined, boiler wash-out pump, of the Smith-Vaile type, were furnished by the Platt Iron Works.

The Harrison Safety Boiler Works furnished a 28-B, Cochrane, feed-water heater capable of raising the temperature of 30 000 lb. of feed-water from 60° to 212° Fahr. per hour. It is 42 in. square, 90 in. high, contains 20 21 by 15-in. trays, and has a filter bed 42 in. square and 14 in. deep. The exhaust inlet and outlet are 14 in. in diameter; the cold-water supply, 2½ in.; the pump suction, 5 in.; and the returns, 5 in. The construction and operation are similar to those in the main power-house.

The Nordberg Manufacturing Company furnished and erected on foundations provided by the Terminal Company a cross-compound, non-condensing, Nordberg-Corliss, two-stage, air compressor, complete, ready for steam, air, and exhaust connections. The steam cylinders are 15 and 26 in. in diameter, and the air cylinders 14½ and 25 in., with a common stroke of 32 in. When operating at 83 rev. per min. under a steam pressure of 150 lb. per sq. in., this compressor will deliver

1 500 cu. ft. of air per min. at a pressure of 120 lb. When operating under the foregoing conditions the steam consumption will not exceed 6.6 lb. for every 100 cu. ft. of air compressed. The construction and operation of, and equipment supplied with, this compressor are similar to that in the compressors furnished by the same company for the main power-plant, and more fully described under that head.

A tubular, water-cooled after-cooler, consisting of a metal cylinder fitted with 234 1-in., seamless, drawn-brass tubes, 7 ft. 2 in. long, presenting a cooling surface of 450 sq. ft., was also furnished by the same company for drying the air before it is sent out for use in the yards and shops.

The Westinghouse Electric and Manufacturing Company furnished three 50-kw. motor-generator sets, each consisting of one 50-kw., type-S, compound-wound, 250-volt, direct-current generator, mounted on a common bed-plate and shaft with one 75-h.p., type-CCL, 2 300-volt, 3-phase, 60-cycle, induction motor. These generators have a rating of 200 amperes and 250 volts, and a speed of 690 rev. per min. Their efficiency at normal voltage and speed is 88% at half load, 90.5% at three-quarters, and 91% at full load. They are guaranteed to run for 12 hours under full load without sparking, and with no serious sparking if the load is increased 75% temporarily. The temperature of any part of the generator when operated under full load for 24 hours will not rise more than 35° cent., except the commutator, which should not exceed 40° cent. above the surrounding atmosphere of 25° cent.

The 75-h.p. motor has a frequency of 7 200 alternations per min., or 60 cycles per sec., a speed of 720 rev. per min. at no load and 690 at full load. Its efficiency is 85% at half load, 86% at three-quarters, and 86.5% at full load. The temperature changes will not exceed 40° cent. for normal conditions.

The 2 300-volt, 3-phase, 60-cycle current received from the main power-plant is converted to 220-volt, direct current by these motor generators, and at this voltage is distributed to the various machines operated by variable-speed motors. The constant-speed machines are driven by 3-phase, 60-cycle, 220-volt, induction motors, the current for which is obtained by stepping down the 2 300-volt, 3-phase, 60-cycle current through oil-cooled transformers.

The chimney for this plant was built by the Alphons Custodis Chimney Construction Company. The octagonal foundation, 20 ft. in

diameter and 6 ft. deep, was built by the building contractor. The chimney proper is 125 ft. high. The base is octagonal, and extends to a height of 25 ft. with 24-in. walls of hard, well-burned, red brick; above this point the chimney is of buff perforated blocks of the Custodis pattern. It is circular in plan, and divided into six sections: five of 16 ft. 5 in., and one of 17 ft. 11 in. The walls vary in thickness from 17 in. in the first section above the base to 7½ in. at the top. The chimney is lined to a height of 60 ft. with 4-in. fire-brick, the lining being divided into sections corresponding to those of the outer wall. There is a 2-in. air space between the walls. The flue opening is 4 ft. 8 in. wide and 8 ft. 2 in. high, strengthened at the top and bottom by 6-in. I-beams built into the brickwork.

Of the foregoing structures, the cleaners' building, the coach yard oil-house, the bedding sheds, the carpet-cleaning shed, and the coach yard power-house were erected by Edward Brady and Son, of Baltimore, Md., the other buildings by Wells Brothers Company, of New York City.

Shop Machinery and Tools.—Table 5 is a list of the machinery and tools in the machine and blacksmith shop and in the car-repair shop, all of which are operated by 220-volt alternating- or direct-current motors. The machines operating at constant speed have 3-phase, 60-cycle, 220-volt, induction motors, those operating at variable speeds have 220-volt, direct-current motors.

General Grading and Masonry.

The contract covering the grading, masonry, and drainage of the north approach to the Union Station was let to McMullen and McDermott and the Hoffman Engineering and Contracting Company, joint contractors, of Philadelphia, Pa., on July 21st, 1903. The grading aggregated more than 3 000 000 cu. yd., the masonry more than 160 000 cu. yd., foundation excavation more than 186 000 cu. yd., and nearly 1 900 tons of iron pipe were used for drainage.

The greater part of the excavation was in the coach-yard section, the average depth of cut over a large area being about 50 ft., with a maximum of 82 ft. In one cut in the heart of the coach yard, there were about 2 250 000 cu. yd. This material was excavated by 70-ton steam shovels, and moved by narrow-gauge dump-cars, of 4 cu. yd. capacity, and narrow-gauge Baldwin locomotives. A portion of the

material was utilized in forming the roadbed between the retaining walls on the approach and train-yard sections, for filling in and around the station foundations and walls, in forming the plaza in front of the station, and in filling the streets leading to it; the remainder was wasted wherever waste banks could be secured. Approximately half of the excavated material was utilized by the Terminal Company; the other half was moved as an expense. In disposing of the material, the average haul was about 1½ miles.

TABLE 5.—MACHINERY AND TOOLS IN MACHINE AND BLACKSMITH SHOP AND CAR-REPAIR SHOP.

Machine.	Size.	Make.	Motors.
MACHINE AND BLACKSMITH SHOP.			
4 Engine lathes	16-in. by 6-ft	Lodge & Shipley	D. C.
1 Engine lathe	20-in. by 12-ft	Lodge & Shipley	D. C.
1 Engine lathe	27-in. by 16-ft	Lodge & Shipley	D. C.
1 Engine lathe	36-in. by 16-ft	Lodge & Shipley	D. C.
1 Turret-head bolt-cutter	No. 4	Pratt & Whitney	D. C.
1 Radial drill	36-in	Bickford	D. C.
1 Full Universal drill	60-in	Bickford	A. C.
1 Boring mill	54-in	Bullard	A. C.
1 Double-head shaper	18-in. by 12-ft	Manning, Maxwell & Moore	D. C.
1 Planer	36 by 36-in. by 8-ft	Pond	A. C.
1 Crank slotter	18-in	Niles-Bement-Pond	D. C.
1 Double-head bolt cutter	1¼-in	Acme	D. C.
1 Standard threading machine	3-in	Cox	D. C.
1 Single emery grinder	No. 3	Bridgeport	D. C.
1 Double emery grinder	18 and 20-in. by 2¼-in	Aumen Machinery Co	D. C.
1 H. & J. Standard punch	No. 3	Manning, Maxwell & Moore	A. C.
1 H. & J. Standard shear	No. 4	Manning, Maxwell & Moore	A. C.
1 Steam hammer	1 500-lb	Niles-Bement-Pond	
1 Driving-wheel lathe	90-in	Niles Bement-Pond	D. C.
1 Planer	42 by 42-in. by 10-ft	Niles-Bement-Pond	A. C.
4 Portable forges	No. 3	Buffalo	
1 Steel pressure blower	No 4	B. F. Sturtevant & Co	D. C.
1 Jib crane (hand-power)	7-ton	Whiting Fdry. Equip. Co	
1 Electric traveling crane	10-ton, 3-motor	Niles-Bement-Pond	
CAR-REPAIR SHOP.			
1 Car-wheel lathe	42-in	Niles-Bement-Pond	D. C.
1 Double-head bolt-cutter	2-in	Acme	D. C.
1 Double-axle lathe		Bridgeford	A. C.
1 Hydrostatic wheel-press	48-in., 300-ton	Niles-Bement-Pond	A. C.
1 Car-wheel borer	48-in., No. 2	Putnam	D. C.
1 Saw-filer and setter		Dietrick & Harvey	
1 Combined gainer and mortiser	No. 512	Greenlee Bros. & Co	A. C.
1 Friezer and shaper	No. 8	Fay & Egan	A. C.
1 Smoothing and finishing planer	30 in	Bentel & Margedant	A. C.
1 Heavy band-saw	No. 311, 36-in	Smith Machine Co	A. C.
1 B. & S. grindstone	40 by 5-in	Hill, Clarke & Co	A. C.
1 Wood trimmer	No. 1	Oliver	
1 Pattern-maker's lathe	20-in. by 9-ft	Oliver	D. C.

The grading equipment consisted of six 70-ton, steam shovels, equally divided between the Vulcan and Bucyrus types, one Thew shovel for street work, about 250 dump-cars, and 20 dinky locomotives.

The mass of the masonry was between Florida Avenue and the station, and the equipment for its construction consisted of two cubical and one Hains' concrete mixers, about 40 derricks, of the guy and stiff-leg types, of from 10 to 15 tons capacity, operated by three-drum, 7¼ by 10-in., hoisting engines, and the usual trucks and buckets for handling the various materials.

The booms of the derricks, many of which were 65 ft. long, were swung by 10-ft. bull-wheels at the bases of the masts. Most of the wheels were made of light T-rails bent to a circle; they rendered very efficient service.

The same contractors, under other contracts, executed all work in connection with the construction of the conduit system for the protection of the telephone and telegraph lines, the power lines between the power-house and the station and coach yard, and the wires used in the battery-charging layout in the coach yard, and furnished all labor and material required in the jacketing of the steelwork in the New York Avenue Bridge.

First Street Tunnel.

As noted elsewhere, the south approach to the Union Station is by way of a tunnel under Capitol Hill, a short section of open cut near the south portal, and an elevated structure at the connection with the Philadelphia, Baltimore, and Washington Railroad tracks on Virginia Avenue. The tunnel proper is 4 033 ft. long. Of this distance, 1 127 ft. at the south end is on a 4° 20′ curve passing under public streets and private property from First and B Streets, S. E., to the intersection of the west side of New Jersey Avenue and the south side of D Street, the remainder is on a tangent parallel to and 25 ft. west of the center line of First Street.

The approach to the tunnel, between the elevated structure over South Capitol Street and the south portal, is on a 1.5% descending grade, changing at that point to a 0.13% ascending grade through the tunnel. The depth of cut for some distance from the south end of the tunnel was barely sufficient to permit its construction below ground. At the north end, for a distance of 330 ft., the top of the tunnel is above the original surface of the street. At East Capitol Street the depth of sub-grade is 63 ft. below the surface of the street. On this account, and to facilitate ventilation, the tunnel was con-

PLATE XIII.
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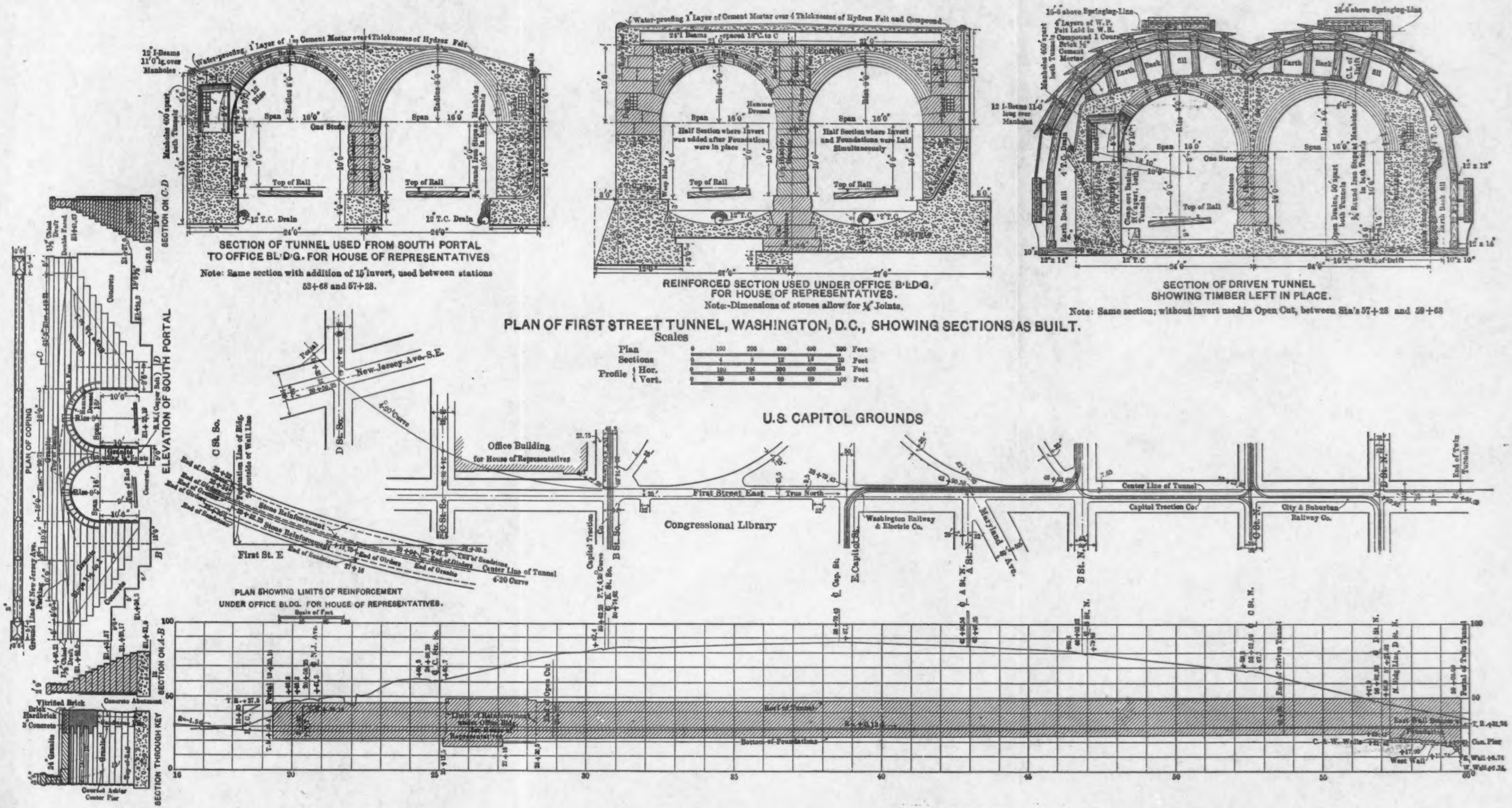

structed of two separate single-track tubes, side by side, the center or dividing wall being 4 ft. thick and having openings at intervals of 100 ft. to serve as refuge niches and means of communication between the tunnels. Each tube has a span of 16 ft. and a height of 17 ft. above top of rail. The center wall is of stone masonry, the side-walls and haunching of concrete, and the arches of brick.

The features of special interest in connection with this work, which are treated more or less in detail in this paper, are the methods of excavating and timbering, disposition of spoil, traveling derricks and centers used in the construction of stone, concrete, and brickwork, the facilities for storing and handling materials, and the plant for mixing concrete. Attention is especially called to the extensive use of machinery on the work, and particularly to the use of electricity and compressed air in the operation of the machinery.

The material overlying the tunnel consisted of a mixture of clay and gravel, with a layer of white sand of varying thickness at about the elevation penetrated by the tunnel. At some points it extended below sub-grade, at others it was found near the top of the tunnel. Below the sand there was a stratum of hard blue clay which in some cases extended some feet above sub-grade.

The sand and gravel overlying the blue clay contained large quantities of water, and, when the sand was thoroughly saturated, produced practically a quicksand. For the purpose of draining the soil on the drift portion of the tunnel, two 6 by 8-ft. shafts were sunk, the bottoms of which were carried well below the grade of the tunnel. One sump was about 1 800 ft., and the other 2 700 ft. from the south portal. These sumps drained the soil so that the excavation was removed with comparative ease. The water was removed from the sumps by pulsometers.

Of the total length of the tunnel, 952 ft. at the south end and 600 ft. at the north end were constructed by the cut-and-cover method. The general excavation of the cut-and-cover section was removed by a Vulcan Little Giant steam shovel operated by compressed air. This shovel operated a 1¼-yd. dipper through a vertical range of 12 ft. and a horizontal range of 16 ft.

The excavated material was deposited directly in 3-yd. wooden dump-cars on a 3-ft. gauge track, laid in a trench beside the shovel. The trains, of from 3 to 6 cars, were taken to the foot of a trestle

incline by electric mine motors made by the General Electric Company. From this point they were hauled up the incline by a cable drawn by a single-drum, Lidgerwood, hoisting engine operated by a General Electric motor. At this point the material was dumped into special 20-yd., standard-gauge dump-cars owned by the contractors, and transported by the Terminal Company to waste banks and fills along Maryland and Virginia Avenues and on the approach to the Potomac River Bridge.

To maintain street traffic over the cut-and-cover section at the south end, a temporary bridge was built at the intersection with C Street in advance of the excavation. Bearings for this bridge were prepared outside the line of cut, and trenches were dug for the lower chords of the structure, so as to place the floor near the original street surfaces. A temporary footbridge, supported on bents, was constructed on the line of New Jersey Avenue. As promptly as possible after the trenches were excavated to grade at these crossings, sections of the permanent masonry were built and back-filled so as to permit the restoration of the street surface. The construction of the intervening masonry was carried on in such a manner as to conform to the logical progress of the work.

Special attention is now directed to the method of excavating the drift-tunnel. On account of the treacherous condition of the material to be penetrated, it was not considered prudent to attempt to carry on the excavation for both tubes simultaneously. Accordingly, the work on each tube was carried on independently. Side-drifts, 4 ft. 6 in. wide and 8 ft. high, with a crown-drift, 6 ft. 6 in. wide and 8 ft. 8 in. high, were first excavated and timbered for one tube, the frames being of 10 by 10-in. timber, and the lagging of 3 by 8-in. planks in 6-ft. lengths.

The headings were excavated by hand, by miners and helpers using picks and shovels. The excavated material was removed from the drifts in small cars on 20-in. gauge, industrial tracks. This work was carried on continuously throughout the 24 hours in three 8-hour shifts, about 10 ft. constituting a day's work. Following the excavation of the top drift, two crown-bars, about 12 in. in diameter and 24 ft. long, were placed in the heading and supported by posts resting on the sills of the drift-frames. Then 3-in. lagging was driven above the crown-bars into the sides of the drift, and all timber but the top of the orig-

FIG. 1.—WASHINGTON TERMINAL STATION: SOUTH PORTAL OF FIRST STREET TUNNEL.

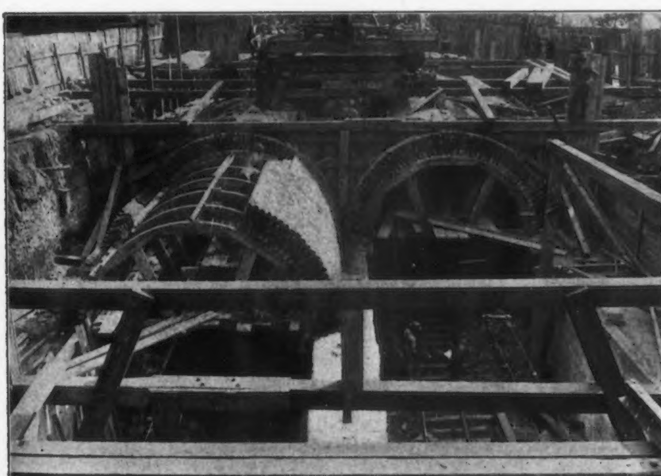

FIG. 2.—VIEW OF CONSTRUCTION OF ARCHES IN OPEN-CUT SECTION.

inal drift was removed. Sufficient material was then removed to provide space for two more crown-bars, which were supported on posts resting on the earth core. Lagging was again driven, and the process of excavating and timbering was continued until approximately the elevation of the springing line of the finished arch was reached. While the enlargement of the top heading was in progress, concrete footings were placed in the side-drifts in such a way as to clear the foundation lines of the permanent masonry. The posts supporting the crown-bars were then replaced by a segmental timbered arch carried down to the concrete footings in the side-drifts. The segmental timbers were 12 by 12-in. and spaced at a normal distance of 30 in. between centers, but where heavy ground was encountered they were spaced at 15-in. centers.

The core was then removed by steam shovel, and the masonry lining put in place. While the lining of the first tube was in progress, the top- and side-drifts of the other tube were being excavated, followed by the placing of crown-bars and the widening of headings as above described. The crown-bar supports were then replaced by segmental timbers, in the usual manner, except that in this case the arch timbers abutted against the concrete filling or haunching above the center-wall on one side, and the other was carried down to the concrete footing in the side-drift, as in the first instance. Following the completion of the timber arch, the core was removed, as for the first tube. The excavation of the core in the first instance covered the removal of about 23 cu. yd. per lin. ft.; in the second case about 11 cu. yd. per lin. ft. were removed.

In addition to the large drainage sumps previously mentioned, there were small sumps in the side-drifts, from which a Snow pump, operated by compressed air, forced the water through a 3-in. pipe to a large sump in the rear of the core excavation. From this point a centrifugal pump, operated by electricity, discharged the water through a 3-in. pipe to a point outside the tunnel. The pump and motor were mounted on a timber platform which permitted it to be shifted readily as the work progressed. The material in the drift-tunnel was disposed of as described under open-cut excavation.

A traveling, stiff-leg derrick with two 40-ft. booms was used for building the center- and side-walls of the open-cut work. This traveler consisted of a platform, about 20 ft. wide and 30 ft. long,

resting on four wheels operating on a 16-ft. gauge track. The track was carried on a falsework of timber bents and vertical posts, utilizing as much as possible the shoring used in connection with the excavation of this portion of the tunnel. The booms were at the front corners of the platform, swung by bull-wheels, and operated by two 3-drum, Mundy, hoisting engines at the rear of the platform. As the traveler advanced in the construction of these walls, the rear bents were taken down and set up in front.

For executing similar work in the drift-tunnel, a traveler having a platform 16 ft. wide and 20 ft. long was used. This traveler operated on a 14-ft. gauge track, laid on the floor of the tunnel, and handled the ashlar and concrete for the center- and side-walls from the material cars to the workmen on the walls. The stiff-leg derricks were on the platform, as before described, but the platform was about 10 ft. above the track, leaving room for the free movement of material cars below, and the masts and booms were only about 5 ft. long. By the use of this style of derrick about 15 ft. of side- and center-walls were completed in a 10-hour shift.

This derrick operated about 100 ft. behind the steam shovel, and about 100 ft. behind it followed the arch-roof construction. For executing this work, a traveling center 20 ft. long and 16 ft. wide was used, the construction of which was similar to that of the traveling derrick, but it carried the arch ribs instead of derricks, etc. The ribs of the center were set 4 ft. apart, and were wedged from the traveler platform. By removing the wedges, the centers were moved ahead without being taken down. The lagging for the arch ribs was of 2½ by 3-in. material. A 20-ft. section of arch was built in one 10-hour shift.

After each section of arch had been completed, and before the centering was removed, the concrete backing was placed and waterproofed, and the space between the top of the masonry and the timber was back-filled with earth and tamped. The concreting and back-filling was done with a machine consisting of a platform mounted on wheels, of the same general construction as the platform of the derrick and center travelers. On the front end of this platform there was a stationary hoist, and behind it a belt conveyor. The latter was pivoted near the forward end so as to allow it to swing to the right or left on a circular track near the rear end. Near the forward end

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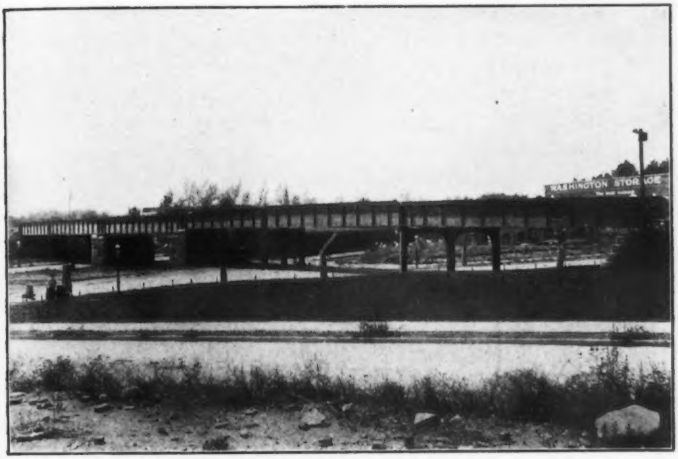


FIG. 1.—WASHINGTON TERMINAL STATION: STEEL VIADUCT OVER SOUTH CAPITOL STREET.

FIG. 2.—WASHINGTON TERMINAL STATION. LOOKING EAST ON VIRGINIA AVENUE.

of this conveyor there was a 30-cu. ft. hopper, from the bottom of which a belt conveyor carried the material into the space above the roof arch on a cantilever arm.

In operating this machine the material bucket was lifted from the car beneath, carried back on the trolley beam over the hopper, and there dumped by hand. From this hopper the material fell upon the belt conveyor and was carried back over the arch and deposited ready for tamping. The hoisting engine on this machine was a Lambert, driven by a 15-h.p. electric motor. The belt conveyor was 20 in. wide, and was operated at a speed of 180 ft. per min. by a 7½-h.p. electric motor. This apparatus required two men to operate it, and is estimated to have saved the labor of 12 shovelers.

The top of the finished masonry was water-proofed with four layers of Hydrex felt laid in water-proof compound. On the cut-and-cover section it was protected by 1 in. of cement mortar, on the drift section by a course of brick covered with a ½-in. coat of cement mortar. After the masonry construction for the first tube was completed and water-proofed, crown-bar supports were again introduced for the purpose of preventing settlement when the segmental timbers were cut in placing timbers in the second tube. When the masonry in the second tube was completed the crown-bars were supported as above.

As the bulk of the work had to be executed from the south end, it was considered economical to make a liberal expenditure at the outset to avoid expensive repairs and alterations as the work progressed. Therefore, electric motors were adopted for all machinery except the shovel, which was operated by compressed air. Enough duplicate motors, etc., were provided to take care of the usual break-downs, so as to avoid interruptions.

A contractors' yard was established on an irregular-shaped property near the south portal of the tunnel. On this property were the general supplies, repair shops, mechanical plant, storage yards, concrete plant, and incline hoist for handling the excavation. The tracks and structures were arranged to provide the most convenient and economical means of handling the material which the shape of the limited space would permit. The standard and narrow-gauge tracks were grouped to furnish access to the various yards and structures, as the conditions required. The yard was lighted by arc lamps distributed over

the property, and, like the motors, were operated by current purchased by meter from the Potomac Light and Power Company.

Stone, lumber, and other heavy materials were handled by derricks operated by electric motors; lighter materials were moved by hand. Crushed stone, gravel, and sand were delivered at the mixing plant in dump-cars and by wagons, and after being dumped into the track hoppers were handled entirely by machinery. The cement was delivered in cars and stored in a house, the floor of which was about 4 ft. 6 in. above the top of rail of the adjacent track. The stone, gravel, and sand were discharged from the track hopper into a bucket conveyor, carried to the top of the mixer, and dumped into a hopper of about 2 cu. yd. capacity. The bottom of this hopper was fitted with an L-shaped cast-iron spout which was arranged to revolve about its vertical axis. By this arrangement material could be directed to four different chutes leading, respectively, to the trestle conveyor and the three elevated storage bins for sand, gravel, and stone.

When the materials were not needed for immediate use in the concrete mixer, the swivel spout delivered to the conveyor on the top of the storage trestle. This conveyor had a movable dumping device, which enabled it to discharge automatically into any of the storage bins beneath. At other times the swivel spout was set to deliver into the storage bins at the top of the mixing tower. As the cement was needed, the bags were carried up an incline by warehouse trucks and placed on a belt conveyor, which carried them to the floor of the mixing tower. The only hand labor then required was the untying and emptying of the sacks into the mixing hopper.

The storage trestle, 175 ft. long, consisted of a series of timber bents, about 40 ft. high, made of 8 by 8-in. posts, caps, and sills, with transverse and longitudinal bracing arranged to make alternate towers and open panels. Every other bent was boarded up, to a height of about 20 ft., to form separate bins for the various materials used for concrete and mortar. A 7 by 6-ft. timbered longitudinal trench was constructed under the storage bins throughout the entire length. It contained a belt conveyor which delivered to a cross-conveyor under the tower, which in turn delivered to a bucket conveyor near the one connecting with the track hopper. The roof of this tunnel formed part of the floor of the storage bins above. There were cast-iron scuppers, with 10 by 12-in. cast-iron gates, at intervals of

FIG. 1.—STEAM SHOVEL REMOVING CORE IN DRIFT-TUNNEL, WASHINGTON TERMINAL STATION.

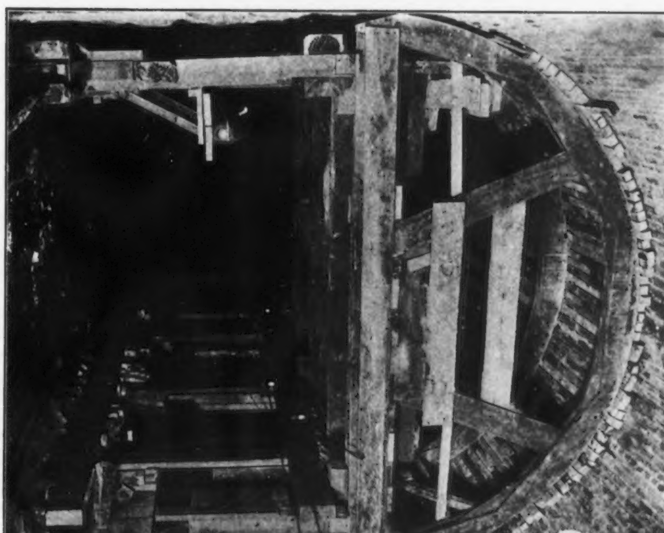


FIG. 2.—INTERIOR VIEW OF FINISHED TUBE, SHOWING TRAVELING CENTER, WASHINGTON TERMINAL STATION.

7 ft. along the center line of the tunnel over the belt conveyor. These gates were operated by hand-levers attached to racks and pinions. When materials were required from the storage piles, the scupper gates were opened, allowing the material to fall on the conveyor and be carried to the respective storage bins in the mixing tower.

The bottoms of these bins were closed by cast-iron gates operated as above. They were arranged to discharge into opposite sides of a mixing bin divided into two compartments corresponding to the different proportions of the materials used in the concrete mixture. When the compartments were filled, the gates were closed, the cement was placed on top, and the contents were dumped into a 1-cu. yd. Smith mixer by the attendant on a lower platform, who operated the hopper gates.

The water used in mixing concrete was supplied by gravity from a 500-gal. storage tank, about 5 ft. above the mixing platform, and filled from the city mains through a ball-cock. From the bottom of this tank a 4-in. pipe, controlled by a special gate-valve, led to a 200-gal. measuring tank into which it discharged through a ball-cock. It was adjusted to close when the tank contained the quantity of water requisite for a batch of concrete of a given consistency. There was also a special gate-valve on the outlet pipe from the measuring tank.

The stems of the special gate-valves were operated by separate horizontal levers, the free ends of which were connected to a vertical rod which passed through the floor of the tank-room and terminated within reach of the attendant in charge of the mixers. When the handle was pulled downward the valve on the outlet pipe of the supply tank was closed and the one on the outlet pipe of the measuring tank was opened, allowing the contents of the latter to flow into the mixer. When the handle was pushed upward it reversed the valve and permitted the tanks to fill.

The mixers were in duplicate, one was generally used for mixing concrete, the other for mortar. The chute from the mixing hopper was arranged so that one or both mixers could be used for concrete or mortar. They were dumped by hand by revolving them on their horizontal axes by a worm-gear, and discharged through an opening in the floor of the platform into 1-cu. yd. steel buckets on small flat cars. At rush times, when both mixers were used, one was being

charged and mixed while the other was being discharged. In this way the capacity was doubled. Each mixer was belt-connected with a 30-h.p., 500-volt, Sprague, electric motor making 750 rev. per min. Clutches were provided for connecting the free ends of the mixer shafts when desired.

The forms for the side-wall construction were of ¼-in. steel plates, 4 ft. wide and 10 ft. high, stiffened by angle-iron flanges on all edges and by three horizontal angles across the plate, dividing the height into four equal spaces. The vertical flanges had 3½ by ¼-in. plates riveted to them and planed to make accurate joints between the several sections of the forms. The sections were joined by bolting the angle flanges together, using as many sections as might be required to cover the distance to be concreted, usually 20 ft.

The forms were braced and stiffened with a continuous line of 6 by 10-in. timbers bolted to the middle horizontal angle. The braces between this timber and the ground were set at an angle of about 45°, and spaced at intervals of about 4 ft. The lower edges of the forms were wedged and braced to the ground or by timbers carried across the cut, the top edges by horizontal struts reaching across the trench high enough to clear the motors and cars. Braces were also placed between the faces of the forms and the vertical side of the excavation, and removed as the concrete was placed.

Concrete inverts were built in the section of the open-cut work under the House of Representatives' Building, and in the entire drift-section. Drainage was provided by placing 12-in. terra cotta pipes in each tube throughout the entire length of the tunnel. Connected with these drains or with the inverts there are 4-in. drains, at intervals of 50 ft., for catching the drainage from the top of the arch and from a point near the elevation of the top of the drain. There were clean-out basins in the drift-tunnel at intervals of 200 ft. in both tubes.

Special construction was used where the tunnel passes under the office building of the House of Representatives, consisting essentially of widening and deepening the footings, the introduction of stonework in the side- and center-walls above the springing line, and reinforcing the top of the tunnel by 24-in. I-beams spaced at 18-in. centers.

In addition to the plant already described, the contractors had one steam locomotive, twelve 20-cu. yd. special dump-cars built by the

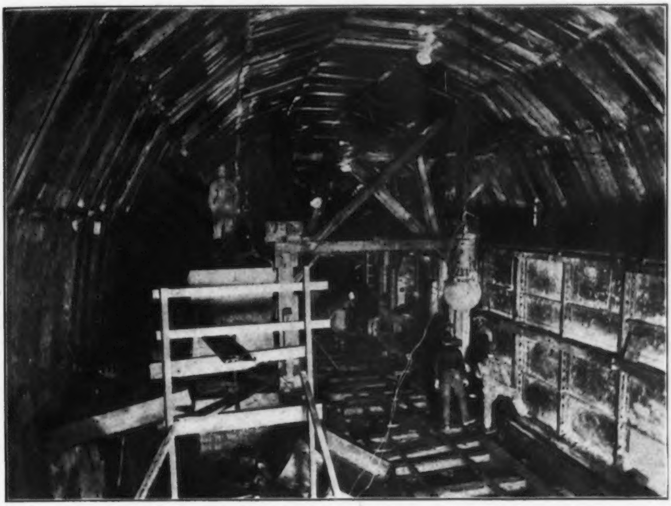


FIG. 1.—WASHINGTON TERMINAL STATION: TRAVELING DERRICK USED IN CONSTRUCTION OF SIDE- AND CENTER-WALLS.

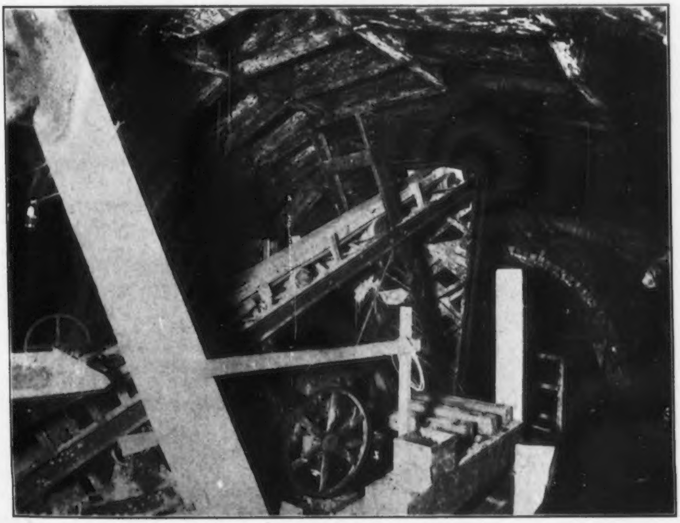


FIG. 2.—CONVEYOR USED IN FILLING OVER TOP OF ARCHES IN DRIFT-TUNNEL, WASHINGTON TERMINAL STATION.

Georgia Car Company, eight Ryan and McDonald, 3-cu. yd., wooden, side-dump-cars, ten 2-cu. yd., wooden dump-cars, four stiff-leg derricks in the storage yard, five Mundy, double-drum hoisting engines, operated by Westinghouse electric motors, two electric mine motors, and the usual small tools.

The foregoing work was executed by the New York Continental Jewell Filtration Company, under a contract dated December 10th, 1903. The excavation for the open-cut work was begun on December 6th, 1903, and the drift-tunnel on October 11th, 1904. The west tube of the tunnel was completed on May 10th, 1906, the east tube on September 6th, 1906.

BELLMOUTH.

The construction between the north end of the twin tunnels, 275 ft. north of the center line of D Street, and the face of the station, consists of a girder-covered bellmouth, about 525 ft. long, and ranging in width from 36 ft. at the junction with the tunnels to 116 ft. 6 in. at the south line of the station. The roof consists of 30-in. transverse girders at intervals of 20 ft., between which there are framed 20-in. I-beams, at 3-ft. centers, covered with ⅜-in. steel buckle-plates.

This construction is supported on the masonry side-walls defining the limits of the bellmouth and on masonry pedestal walls and columns, arranged to suit the track layout. The tracks provide for train movements from each tube to any of the six tracks under the station, which in turn connect with the nine low-level tracks in the train yard. The masonry side-walls are of sandstone ashlar with Portland cement backing and foundations. The pedestal walls are of double-faced sandstone ashlar on Portland cement concrete foundations.

The elevation of the original ground varied from about +22 at the face of the station to +38 at the end of the twin tunnels between D and E Streets, N. E., and the top of the masonry walls varied from about +54 at the face of the station to +51 at the end of the tunnel. It will be noted, therefore, that nearly the entire bellmouth proper was built above the original ground, and that the tracks were laid on a fill ranging from 0 at a point about 200 ft. north of the south end of the bellmouth to about 10 ft. at the station line or north end.

On account of unstable foundation material, however, the masonry was carried in a number of cases to a depth of about 14 ft. below the

original ground, the average depth being about 12 ft. The fact that it was not necessary to excavate below the original surface in the preparation of the roadbed greatly simplified the matter of drainage in the bell-mouth and, particularly, the depressed ventilating ducts, which were drained either into the reconstructed sewer under the plaza or into original sewers which were not disturbed.

All the steelwork, including girders, I-beams, buckle-plates, and columns, is encased in concrete. The minimum thickness of concrete over the top of the structure is 3 in., with a crown of 6 in. at the center. The entire top surface is water-proofed with four layers of Hydrex felt and compound, as applied in the tunnel, and protected with a 1-in. layer of cement mortar. The lower flanges of all beams are encased in Clinton wire cloth, as a reinforcement for the concrete protection.

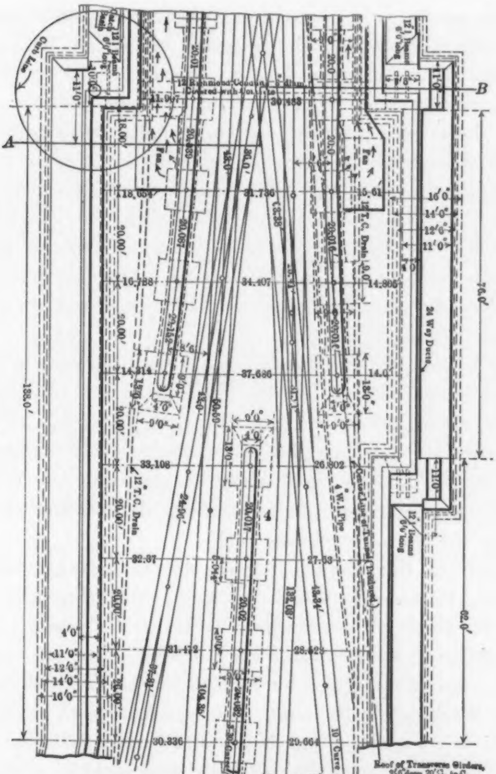
In the construction of the side-walls of the bellmouth, provision was made for putting in a ventilating plant at a point about 200 ft. north of the end of the twin tunnels, the details of which are described under that heading.

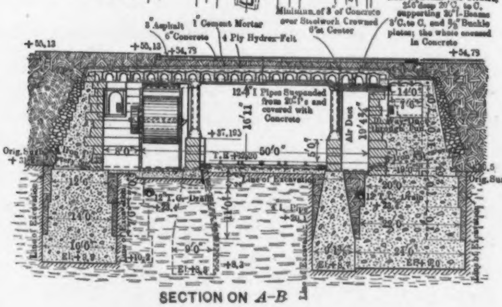
The general excavation was started on July 16th, 1904, and completed on August 9th, 1904; the masonry was started on September 23d, 1904, and completed on January 31st, 1906; the erection of the superstructure was started on April 30th, 1905, and completed on August 30th, 1906.

The building of the masonry retaining and pedestal walls and the jacketing of the steelwork with concrete was done by McMullen and McDermott and the Hoffman Engineering and Contracting Company. The steelwork was furnished by the American Bridge Company, and erected by Brann and Stuart, of Philadelphia, Pa.

Ventilating Plant.

The development of the plans in connection with the reconstruction of the railroad terminals in Washington was based on the use of steam power in the handling of all regular trains and light equipment, to and from the terminal depot, in the passenger and freight yards, and through the First Street Tunnel. To avoid the smoke nuisance, so prevalent at all railroad terminals operated by steam power, provision was made for the use of coke on all yard engines, and the road engines had a supply of the same fuel for use within the District of Columbia.





SECTION ON A–B

FIG. 9.

Thus the smoke nuisance was abated, but the steam and gases emitted by the locomotives in the passenger and freight terminals, and the north and south approaches to the passenger depot, were left to be handled in another way. Had one large shed or a series of closed sheds been constructed over the station tracks, new difficulties would have been presented, but, on account of the use of the umbrella sheds, with ample space between, this difficulty was easily overcome, and, for the purpose of removing the steam and gases from the tunnel, the bellmouth, and the track space under the station, a ventilating plant was placed in the bellmouth about 200 ft. north of the north end of the twin tunnels. The plant consists of two electrically-operated fans, and the necessary ducts.

Before the adoption of this scheme, however, the kind of power to be used was considered, and it was the consensus of opinion of the owning and tenant companies that the time had not arrived when steam power could be, for any logical reason, economical or otherwise, supplanted by any other kind of power at this point, except, perhaps, on the score of cleanliness, and it was felt that this could be greatly improved by the use of smokeless fuel.

In support of this opinion it was pointed out that the use of electric power, for example, would require the establishment of separate locomotive terminals at or near the District limits, where intersected by the Washington and Metropolitan Branches of the Baltimore and Ohio Railroad and the Magruder Branch of the Philadelphia, Baltimore, and Washington Railroad, and at some point south of the Potomac River for the accommodation of all roads entering from the south; and, further, that the delay to all trains incident to the change from steam to electric locomotives, and *vice versa,* upon reaching or leaving the District, would cause a loss of time which would not be justified at present. It was felt, therefore, that, until all lines leading to Washington were electrified and operated so as to permit all trains to enter and leave the station without interruption at the District line, it was imperative that the use of steam power should be continued.

In determining the size and number of fans for the ventilation of the tunnel, the train intervals and the cubic contents of the tunnel and bellmouth were taken into consideration. The reason for adopting the plan of forcing the impure air out of the south end of the tunnel, about 4 240 ft. distant, is obvious. The shortest train interval was

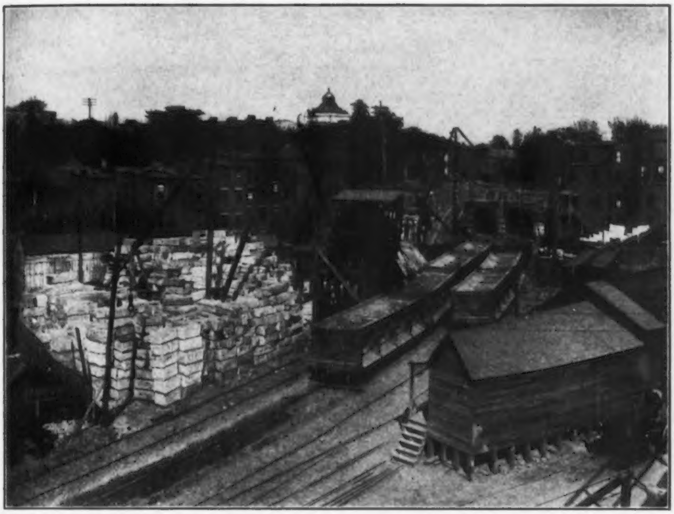


FIG. 1.—WASHINGTON TERMINAL STATION: STORAGE YARD AND ENTRANCE TO TUNNEL, LOOKING NORTHEAST.

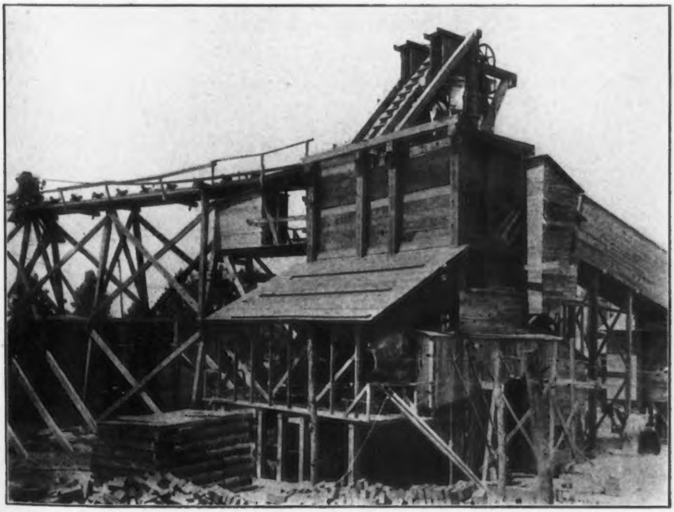


FIG. 2.—VIEW OF MIXING PLANT, SHOWING LOCATION OF MIXERS.

taken as 5 min., and to allow a safe margin it was proposed to clear the tunnel in 4 min. The combined sectional area of the two tubes was about 500 sq. ft. and the length 4 033 ft., thus the volume of air to be changed was 2 016 500 cu. ft. To this must be added the cubic contents of the portion of the bellmouth between the end of the tunnels and the fans, amounting to about 150 000 cu. ft., giving an aggregate volume of 2 166 500 cu. ft.

Having decided on the train interval and obtained the cubic contents of the tunnel, it was found that, to meet the conditions, each fan would have to be capable of discharging about 270 000 cu. ft. of air per min. As the fans were to be placed about 665 ft. south of the north portal or end of the bellmouth, and had to draw their air supply from that point, the contents of this space, amounting to about 1 250 000 cu. ft., had to be taken into consideration.

It will be noted that the cubic contents of the tunnel was about twice the cubic contents of the bellmouth, and that to change the air in the bellmouth would require normally about one-half the time required to clear the tunnel. As the tunnel could only be cleared by forcing other air into it and the bellmouth, by passing the air through the tunnel, the impure air in the bellmouth was used in part to perform this work; but, on account of the sectional area of the bellmouth being about four times the combined area of the twin tunnels, the density of the steam and gases in the bellmouth was only about one-eighth of that in the individual tubes for each train movement.

Had the density of the steam and gases been uniform throughout the entire length of the tunnel and bellmouth, each fan would have been required to discharge an average of about 427 000 cu. ft. of air per min. to clear the entire space in 4 min., as specified. On the basis of clearing the tunnel in 4 min., 2 min. would have been required to clear the bellmouth, and the total time required for changing the air in the tunnel and bellmouth would have been 6 min. As previously stated, however, the air in the bellmouth contained such a small percentage of steam and gases, compared with the tunnel proper, as to make it practically negligible in fixing the capacity of the plant.

The specifications for the plant, prepared by the Motive Power Department of the Pennsylvania Railroad Company, provided that the fans should be capable of delivering not less than 260 000 cu. ft. of

air per min., against a pressure of 1½ in. of water, at a speed of from 135 to 145 rev. per min. at 120 b.h.p. The design of the nozzle and air ducts required to direct the air into the tubes was prepared by Charles S. Churchill, M. Am. Soc. C. E. The plant was made by the Cranford Paving Company, of Washington, D. C.

To meet the foregoing requirements, two fans, with wheels 10 ft. in diameter and 7 ft. in width, were furnished and put in by the Sirocco Engineering Company. They are operated by two 125-h.p., 2 300-volt, induction motors, made by the General Electric Company.

The discharge orifices of the fans are 8 ft. wide and 8 ft. 6 in. high, and have dampers which can be raised or lowered to vary the volume of the air discharged. These orifices are connected with the main ducts constructed along the side-walls of the bellmouth, and extend from the fans to a cross-duct beneath the tracks at a point about 130 ft. south of the fans. The ducts are 18 ft. 8 in. in height and of varying width, the sectional area ranging from 114 to 190 sq. ft. The area of the nozzle is 118 sq. ft., or 59 sq. ft. for each tube.

The sides are formed by the side-walls of the bellmouth and reinforced concrete curtain-walls built along the line of columns supporting the roof. The floors are of concrete 6 in. thick, and the roofs of ⅜-in. transite supported on T-irons, spaced at 24-in. centers resting on the reinforced curtain-walls and bridge seats. The cross-duct is 8 ft. wide and about 6 ft. 6 in. deep, and extends between the curtain-walls of the side-ducts. It is covered with ½-in. steel plates.

Between the cross-duct and the nozzle the air is split up and made to pass through a number of smaller ducts for the purpose of distributing it so as to have it enter the tunnels around their perimeter. The curtain-walls and supporting columns of the distributing ducts are of reinforced concrete, and all ducts beneath the tracks are covered with ⅜-in. steel plates. The construction above the springing line, conforming in section to the form of the tunnel arches, consists of ⅜-in. transite supported from the ceiling.

The equipment is belt-driven and, as originally built, the fans and motors had pulleys with diameters which drove the fans at 145 rev. per min. When put in operation, considerable trouble was caused by the slipping of the belts, due to the overload of the motor and the low speed of the belts. The original pulleys were then replaced by new ones having diameters of 114 and 27 in., respectively, which gave a higher belt speed and reduced the fan speed to 132 rev. per min.

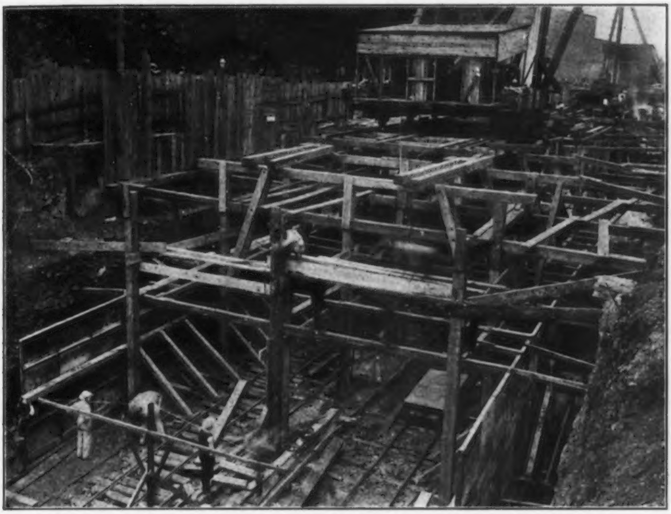


FIG. 1.—WASHINGTON TERMINAL STATION: SETTING STEEL PLATE FORMS USED IN SIDE-WALL CONSTRUCTION, CUT-AND-COVER TUNNEL.

FIG. 2.—VIEW OF MASONRY CONSTRUCTION UNDER HOUSE OF REPRESENTATIVES' OFFICE BUILDING

With the fans operating at the latter speed, tests were made for the purpose of determining the volume of air delivered, the pressure maintained in the ducts, the velocity of air through the tunnel, and the power required to drive the fans. In these tests it was found that the fans exceeded the capacity at which they were rated by the builders by more than 50%, and that, to avoid overloading the motors, it was necessary to reduce the area of discharge.

To reduce the delivery and the consequent consumption of power, the areas of the fan discharges were reduced from 68 to 46 sq. ft. This, however, did not prove an efficient method of reducing the power requirements, and the results of the tests were submitted to the Sirocco Engineering Company, with the request that a speed be recommended which would permit the operation of the fans with the discharge full open and not load the motors beyond their rated horse-power. The Sirocco Company estimated that if the fans were operated at 110 rev. per. min. they should be capable of discharging 320 000 cu. ft. per min. at 125 h.p.

Subsequent tests indicated that at a speed of 114 rev. per min. the fans would deliver 352 000 cu. ft. of air per min. with a power consumption of 89 kw., while the former tests showed a delivery of 400 000 cu. ft. with a power consumption of 175 kw. At 132 rev. per. min. the average velocity of air through the tunnels was about 18 miles per hour, at 114 rev. per. min. it was about 15.75 miles. The tests also showed a variation of approximately 50% in the velocity of the air at the different points of a section. The greatest velocity was noted in the upper portion of the section, the least near the tracks.

To determine whether the velocity of air was uniform at all points, readings were taken in both tubes at intervals of 400 ft., 1 100 ft., 1 600 ft., and 3 700 ft. from the north end of the twin tunnels. While there was more or less variation in the velocity at the different points of the section, the average velocity at all sections was found to be practically uniform. Similar observations were then made with the dampers in various positions, noting the power required, revolutions per minute of motors and fans, temperature of air and motors, and the humidity.

When the fan for the south-bound tube was operated, with the fan for the north-bound tube shut down, 13 kw. more power was required than when the other fan was running. This was due to the air being discharged through the combined nozzle and to the fact that a

portion was discharged through the fan not in motion. The passage of trains in one tunnel affected the draft in the other, due to the air passing through the openings in the middle wall.

It was also noted that a train moving at its usual speed in the north-bound tunnel (against the draft) would stop the draft in the south-bound tunnel and reverse the draft in the north-bound tunnel, and that 4 min. were required to establish the draft at the south portal of the north-bound tunnel and 2 min. for the south-bound after the train had entered the south portal of the north-bound tube. Also that large quantities of steam and gas were forced through the openings in the middle wall into the south-bound tunnel and discharged through that tube. Both tunnels were practically clear within 6 min. after a train entered the north-bound tunnel, and within 3 min. after a train passed out of the south portal of the south-bound tunnel. This seemed to indicate clearly the advisability of placing the fans so as to produce the draft in the direction of the traffic, and the desirability of having a solid wall between the two tubes.

Track Work.

The tracks on the terminal property between the north side of Florida Avenue and the north end of the twin tunnels under First Street were laid with No. 1, Am. Soc. C. E. standard, 85-lb., steel rails. The tracks in the First Street tunnel were laid with No. 1, Pennsylvania Railroad standard, 100-lb., steel rails. With the exception of a small percentage of No. 2, all tracks were laid with No. 1 white oak ties and ballasted with stone. When tracks were laid on fills they were originally ballasted with cinder and later raised on stone.

The tracks on the joint coach and engine yard were laid with Am. Soc. C. E. standard, 85-lb., steel rails, No. 1 being used in all leads, turnouts, and thoroughfare tracks, with No. 2 in the interior tracks. About 90% of the ties used on this section were No. 1 white oak and Georgia yellow pine, the remainder were No. 2 white oak and Georgia yellow pine. All tracks were ballasted with cinder.

The main tracks of the Washington and Metropolitan Branches of the Baltimore and Ohio Railroad, from Florida Avenue northward and eastward, were laid with No. 1, Am. Soc. C. E. standard, 85-lb., steel rails on No. 1 white oak ties, and ballasted with stone. The tracks

of the Magruder Branch of the Philadelphia, Baltimore, and Washington Railroad north of New York Avenue were laid with No. 1, Pennsylvania Railroad standard, 100-lb., steel rails on No. 1 white oak ties, and ballasted with stone. Between Florida and New York Avenues, 85-lb. rails were used in order to avoid changes in frogs and interlocking in connection with the scissors crossing.

The frogs and crossings in all tracks on the terminal property, in the scissors crossing at the throat of the coach and engine yard, and at the east and west ends of the **Y** connecting the Washington and Metropolitan Branches of the Baltimore and Ohio Railroad, except the stub sidings near the power-house and express building, are of manard or manganese steel. All frogs in the coach and engine yard and in the stub tracks above noted, and all switches on the entire improvement are of Bessemer steel.

The object of placing two kinds of special frog construction in the track layout was to test the merits of manard and manganese steel. In order to obtain an unbiased opinion, frogs of each make were placed on either side of a diamond crossing near L Street, where the traffic would be the same on each group. The results, thus far, after two years of service, are very gratifying, but show no advantages of one over the other.

All switch points in the regular turnouts are 16½ ft. long; those in the slip-switches are 15 ft. long. With the exception of a few of No. 7 in the stub tracks, all frogs on the entire passenger terminal are No. 8. The slip-switches in the east and west ends of the **Y** connection are No. 10, all other slip-switches are No. 8. The ends of all stub tracks have Ellis patent bumping posts.

Construction Organization.

Acting under the power and authority vested in the Baltimore and Ohio Railroad Company by the Act of Congress approved February 12th, 1901, relating to the elimination of grade crossings in the District of Columbia, a terminal company was incorporated on December 6th of the same year, for the purpose of carrying out the provisions of the above Act. The entire capital stock issued under the above Act of Congress was owned and held by the Baltimore and Ohio Railroad Company, and the seven directors chosen for the purpose of incorporation were selected from among the officers and employees of that company.

Later, when the bill providing for a union station was prepared, it contained a provision permitting the construction of the station and approaches by the Terminal Company, on condition that one-half the capital stock already issued should be acquired by purchase by the Philadelphia, Baltimore, and Washington Railroad Company, and that it should be entitled to subscribe for and acquire equally with the Baltimore and Ohio Railroad Company any stock afterward issued by the Terminal Company.

When this bill became a law the personnel of the board of directors of the Terminal Company was changed so as to give both companies representation, as their interests might appear. The officers were then selected from among the officers of the two railroad companies, the by-laws providing that under certain conditions the office of President should alternate annually between the Presidents of the Baltimore and Ohio and the Pennsylvania Railroad Companies.

The ownership of the Washington Terminal Company embraces all tracks and property from the north side of Florida Avenue on the north approach, to the south end of the First Street Tunnel on the south approach. It includes, therefore, the sections known as terminal approach, train-shed, depot, and First Street Tunnel, together with all buildings and structures included within those limits. The coach and engine yard is owned jointly and equally by the Washington Branch of the Baltimore and Ohio Railroad Company and the Philadelphia, Baltimore, and Washington Railroad Company, but is operated and maintained by the Terminal Company. The operating and carrying charges of the Terminal Company, covering, as stated before, the depot and approaches, and the joint equipment yard, are prorated against the railroad companies using the facilities on the basis of cars and engines handled for each company.

The main tracks north of Florida Avenue are owned and maintained by the respective roads entering the terminal from the north. The main tracks between the south end of the First Street Tunnel and the connection with the main tracks on Virginia Avenue, over which the trains of all roads entering from the south are handled, are owned by the Philadelphia, Baltimore, and Washington Railroad Company, but operated and maintained by the Terminal Company.

Soon after the selection of the site for the Union Station, the late Mr. Cassatt, then President of the Pennsylvania Railroad Com-

pany, instructed Joseph T. Richards, M. Am. Soc. C. E., Chief Engineer of Maintenance of Way, of the Pennsylvania Railroad Company, to take up with the architects the planning of the station and to prepare and submit for approval, such a track and building lay-out as would make a complete terminal and care for the business handled by the Baltimore and Ohio, and the Pennsylvania Railroads.

In planning all the operating features, Mr. Richards was assisted by Mr. J. R. Wood, Passenger Traffic Manager, Mr. E. F. Brooks, General Superintendent, and Mr. Joseph Crawford, General Agent, all officials of the Pennsylvania Railroad Company, and by Mr. L. G. Haas, Assistant General Manager of the Baltimore and Ohio Railroad Company, who was appointed by Mr. L. F. Loree, then President of the Baltimore and Ohio Railroad Company.

Subsequently, at the request of Messrs. Richards and Haas, Mr. A. W. Gibbs, General Superintendent of Motive Power of the Pennsylvania Railroad Company, and Mr. J. E. Muhlfeld, General Superintendent of Motive Power of the Baltimore and Ohio Railroad Company, were appointed as additional members of the committee, to provide for the power-house and motive power requirements.

On the completion of the general plans and their approval by the Presidents of the respective railroads, the engineering work of the entire project was placed in the hands of the Chief Engineers of the owning companies for construction, with authority to make such subdivision of the work as they saw fit. At that time, the late William H. Brown was Chief Engineer of the Pennsylvania Railroad Company, and the late Joseph M. Graham, M. Am. Soc. C. E., was Chief Engineer of the Baltimore and Ohio Railroad Company.

At a meeting of the Chief Engineers it was agreed that the construction work contiguous to the tracks of the respective companies should be placed under the jurisdiction of the Engineering Departments of these companies. It was also agreed that the design and installation of the machinery in the main power-plant should be handled by the Motive Power Department of the Pennsylvania Railroad Company, while the design and arrangement of the joint roundhouses and shops, and the installation of their machinery should be handled by the Motive Power Department of the Baltimore and Ohio Railroad Company.

As much of the space north of Massachusetts Avenue was either occupied by or contiguous to the Baltimore and Ohio Railroad Com-

pany's tracks and yards, and as the construction of the south approach could be handled to the best advantage from a connection with the Philadelphia, Baltimore, and Washington Railroad Company's tracks on Virginia Avenue, the north line of Massachusetts Avenue was decided upon as the logical dividing line between the work to be handled by the respective companies.

This placed all work north of Massachusetts Avenue, except the north end of the bell-mouth and the design and installation of machinery in the main power-plant, under the jurisdiction of the Engineering Department of the Baltimore and Ohio Railroad Company, with the writer in direct charge, and all work south of Massachusetts Avenue, together with the north end of the bell-mouth, under the jurisdiction of the Engineering Department of the Pennsylvania Railroad Company, with J. T. Stuart, M. Am. Soc. C. E., in direct charge.

The work under the former company embraced a portion of the plaza, the station, train-sheds, approach, express terminal, main power-house, and the K Street and Massachusetts Avenue interlocking towers, on the terminal property, and the coach and engine yard, power-houses, engine-houses and shops, on the joint property, together with the main tracks of the Washington and Metropolitan Branches of the Baltimore and Ohio Railroad Company, and the Magruder Branch of the Philadelphia, Baltimore, and Washington Railroad Company contiguous thereto. The work under the latter company embraced the bell-mouth under Massachusetts Avenue plaza, the First Street Tunnel, the connection between the south portal of the tunnel and the tracks of the Philadelphia, Baltimore, and Washington Railroad Company on Virginia Avenue, and the Magruder Branch east of the old Washington Branch.

The architectural work on all buildings and structures within the terminal area, embracing the station, umbrella sheds and platforms, power-house, express building, and K Street and Massachusetts Avenue interlocking towers, was executed by D. H. Burnham and Company, of Chicago, Ill. This company prepared contract drawings and specifications covering the various classes of work involved, and invited bids. The propositions were addressed to the Chief Engineers of the Pennsylvania and Baltimore and Ohio Railroad Companies, by whom they were opened. The contracts were made by the Terminal Company and executed by its President. The detailed drawings were

then prepared, and the construction was supervised by the architects under the general direction of the writer as the Terminal Company's representative. Under the above organization, work on the general terminal improvements was started in August, 1903. On February 1st, 1904, Mr. Graham resigned as Chief Engineer of the Baltimore and Ohio Railroad Company and was succeeded by the late Daniel D. Carothers, M. Am. Soc. C. E., under whose general direction the work entrusted to the Engineering Department of the Baltimore and Ohio Railroad Company was carried to completion.

On February 1st, 1904, Mr. Stuart resigned and was succeeded by Robert Farnham, Jr., Assoc. M. Am. Soc. C. E., under whose direct supervision the work was completed. On March 28th, 1906, Mr. Brown, having reached the age limit under the rules of his company, was retired and Mr. Alexander C. Shand was appointed his successor. Under his general direction the work placed in charge of the Engineering Department of the Pennsylvania Railroad Company was completed.

Operation Organization.

The operation organization of the Terminal Company consists of a board of managers, a superintendent, an auditor, an engineer, a master mechanic, a ticket agent, a baggage agent, a station master, and a general yard master. The board of managers is composed of representatives of the owning and tenant companies as follows: Pennsylvania, Baltimore and Ohio, Washington Southern, Southern, and the Chesapeake and Ohio, five members in all, reporting to the board of directors of the Terminal Company.

The superintendent is the active head of the organization, and reports to the board of managers. The heads of the various departments report to the superintendent. In addition to performing the duties of that office, the auditor is also superintendent of the terminal relief department. The engineer has charge of all matters pertaining to the maintenance of track, interlocking plants, and structures. The master mechanic has charge of the repairs and general maintenance of equipment, and jurisdiction over the power-stations.

The ticket agent has charge of the sale of tickets for all roads entering the terminal. The baggage agent exercises jurisdiction over the baggage- and parcel-rooms. The station master has charge of the handling of trains in and out of the station, and the general yard

master exercises similar jurisdiction over the handling of trains and equipment in the yards. Each of the above departments is provided with the requisite force of men to perform the duties devolving upon it, to keep the terminal a model of neatness and order.

The duties of treasurer are performed by the treasurer of the Baltimore and Ohio Railroad Company, while those of purchasing agent are performed by the purchasing agent of the Pennsylvania Railroad Company.

Conclusion.

Although incomplete, the terminal was thrown open to the public on Sunday morning, October 27th, 1907, when the Baltimore and Ohio Railroad Company abandoned its station at New Jersey Avenue and C Street and occupied temporary quarters in the east end of the new station. Three weeks later, November 17th, the Philadelphia, Baltimore, and Washington Railroad Company abandoned its Sixth Street station and transferred its traffic to the new station.

As the Baltimore and Ohio Railroad Company was the first tc reach Washington with its railroad and the first to be organized as a transportation company, not only in America, but in the world, it seems but a fitting culmination of this great work, with which it had so much to do, that it should be the first to occupy the new station. October 27th, 1907, will go down in history as marking the date upon which the railroads of the District of Columbia took the final step in compliance with the Act of Congress relating to the elimination of grade crossings in the City of Washington and the District of Columbia.

The old C Street Station, which for so many years served the patrons of the first railroad to reach the National Capitol, has been removed, and the site has been filled to the level of the surrounding streets, in line with the general change in the topography of this section of the city. The Sixth Street Station has also been removed, and all evidence of this once busy center has been obliterated. Its removal will permit the development of the Mall along the lines laid down by the Park Commission.

The Baltimore and Ohio Railroad Company monopolized steam railroad transportation to and from Washington until in the late Sixties, when the Baltimore and Potomac Railroad Company, now the Philadelphia, Baltimore, and Washington Railroad Company, estab-

lished a station south of the Mall, but in 1872 changed its location to Sixth and B Streets, N. W., near Pennsylvania Avenue. The stations of both roads figured conspicuously in many historic events, and many noted personages passed their portals. Their passing brings up many memories, but these will soon fade, leaving but imperfectly written records to enlighten future generations.

In conclusion, the writer wishes to express his high appreciation of the assistance rendered by the officers and employees of the Pennsylvania and Baltimore and Ohio Railroad Companies in the execution of the above work, especially the late Joseph M. Graham and Daniel D. Carothers, former Chief Engineers of the Baltimore and Ohio Railroad Company, and Messrs. William H. Brown and Alexander C. Shand, former and present Chief Engineers of the Pennsylvania Railroad Company, under whose joint general direction the above work was executed, and to Mr. Robert Farnham, Jr., who furnished plans and photographs and otherwise assisted in the preparation of the description of the work on the First Street Tunnel.

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TRANSACTIONS

Paper No. 1181

THE TIETON CANAL.*

By E. G. Hopson, M. Am. Soc. C. E.

With Discussion by Messrs. Horace W. Sheley, H. F. Dunham, and E. G. Hopson.

The Tieton Project of the United States Reclamation Service derives its water supply from the Tieton River, in the State of Washington, one of the feeders of the Naches, the most important tributary of the Yakima. The Tieton River drains a mountainous area of about 250 sq. miles on the east slope of the Cascade Range. Its summer flow seldom falls as low as 200 sec-ft. and then only for short periods, while the maximum flood flow has been estimated at from 14 000 to 20 000 sec-ft. An extensive glacier-covered district at the summit of the mountain range furnishes the bulk of the summer flow, which is distinguished by the turbid or light green color of the water due to glacial material carried in suspension.

The Tieton Project includes some 30 000 acres, mostly of excellent semi-arid agricultural land, lying north and west of the City of North Yakima, in the basin of Cowiche Creek, requiring for its proper development an artificial supply for irrigation during the summer.

The general scheme of the irrigation system is simple, the supply being diverted from the Tieton River at a point some 14 miles above the irrigable lands and conducted in a reinforced concrete conduit or aqueduct along the Tieton Cañon to an elevation sufficient to permit

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*Presented at the meeting of October 5th, 1910.

of piercing the Naches Ridge by a tunnel so as to deliver into the Cowiche Basin for distribution. The diversion of the summer flow of the Tieton River, however, necessitates the construction of compensating storage on the Naches River to satisfy vested rights on the Naches and Yakima Rivers, a reservoir of some 30 000 acre-ft. being now under construction at Bumping Lake for this purpose.

This paper describes the main canal or aqueduct along the Tieton Cañon, several novel features of design and construction likely to be of interest having been adopted on that work.

The Tieton River throughout most of its course flows in a cañon approximately 2 000 ft. in depth. The upper portions of the cañon walls are often vertical, and occasionally bluffs extend down to the stream level, but, as a general rule, the lower slopes consist of accumulated talus material, the product of erosion and disintegration, the slopes being broken here and there by bluffs or outcroppings of rock. The rock formation throughout the length of the canal is eruptive, basalts, lavas, and other volcanic matter being heaped up, intermixed and interstratified according to varied conditions of lava flow and eruptive activity during past ages.

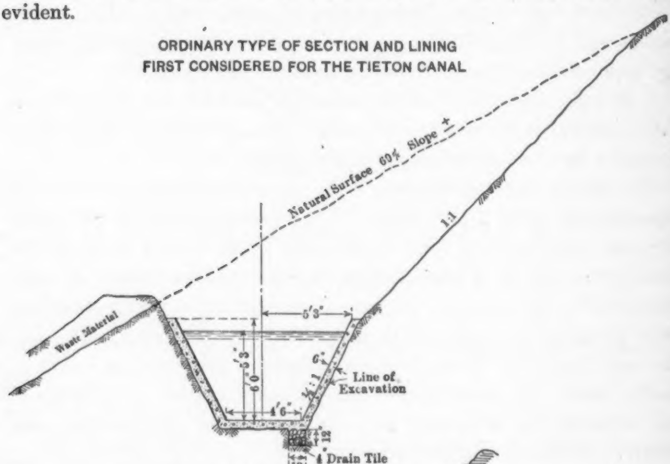
The main canal, with a length of about 12 miles from the diversion point in the river to the lower extremity of the tunnel through the Naches Ridge, encountered practically every variety of material in its course, but at no point excepting in the extreme upper 1 000 ft. was the formation such as to permit of the use of the ordinary type of unlined earth canal.

Surveys made in 1905 and 1906 disclosed the fact that the greater part of the main canal would lie on side-hill slopes averaging close to 60%, that is, with a rise of 6 to a horizontal measurement of 10. The side-hill material for the most part consisted of soils and gravelly clays frequently intermingled with slide rock material and occasionally consisting wholly of slide rock, the latter being the local term for a talus of large rock fragments. The earthy material in the side-hill was found to be generally unstable during the spring, when frost was coming from the ground, and this instability was later found to be particularly noticeable in some of the slide rock material when lubricated by moisture and clay, as was frequently the case.

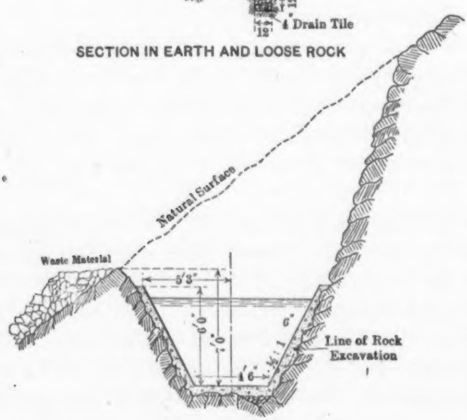
While originally it had been hoped that an ordinary unlined canal section in open cut might be used for much of the work, this idea soon

had to be abandoned, and later it became doubtful whether even ordinary concrete lining would hold the canal intact on the steep side-hill slopes, after their tendency to cave and slide had been made evident.

ORDINARY TYPE OF SECTION AND LINING
FIRST CONSIDERED FOR THE TIETON CANAL



SECTION IN EARTH AND LOOSE ROCK



SECTION IN ROCK

Fig. 1.

Concrete lining used in canal work consists generally of from 4 to 6 in. of concrete applied to the sides and bottom of the excavated trench, as shown by Fig. 1. It had been expected that this method of construction could be used, but, as studies were elaborated and the

nature of the ground was more carefully observed, grave fears were entertained as to its practicability and economy.

The completion of the final surveys in 1906 lent greater weight to these misgivings. The side-hill material *in situ* was found to be mostly at the natural angle of repose, and any considerable disturbance by undercutting the slopes, such as would be necessary for this type of construction, would result in extensive slides until a new condition of equilibrium should be reached. In the spring of 1906 the melting snows and rains had thoroughly saturated much of the upper side-hill material, and, in the light road cuts at the bottom of the cañon, it was observed that heavy sloughing and caving of a highly significant character had occurred.

Later, it was found that much of the supposedly solid rock formation was very little more stable than the earth, the material being frequently fractured and jointed in every direction, with slippery clay seams, and disintegrating rapidly on exposure to the weather.

The conclusions reached during 1906 were:

First.—That the type of canal should preferably involve as little disturbance of the natural side-hill slopes as possible;

Second.—That the canal should be a practically self-sustained structure, capable of resisting considerable external earth pressure on its upper side, and of sufficiently rigid cross-section to retain its integrity against internal hydrostatic pressures without dependence on any support from the outside embankment.

It will at once be seen, by an engineer familiar with standard flume construction in the West, that the flume type more nearly fulfills these requirements than any other, except as to external earth pressures, which do not apply, besides possessing the advantage of a low first cost. Flume construction, moreover, wholly avoids the disturbance of the natural slopes. The most unsatisfactory features of large flume construction are obviously maintenance and periodic renewal. The Reclamation Service has systematically endeavored to avoid temporary types of structures, on this account, unless conditions are such that they have an incontestable economic advantage.

In the vicinity of the Tieton Cañon the lumber most available for flume construction was yellow pine and fir. Of these, red fir was the more desirable because of its superior durability and comparative freedom from warping. It happened, however, that the local supply

of red fir was insufficient for so large a work, and an adequate supply would have necessitated shipments from a distance, at high cost. It was estimated that pine used in a structure of this kind would have an average life of from 10 to 12 years, and, in addition, would require heavy annual maintenance and renewal work. Allowing for complete renewals every 10 or 15 years and necessary repair work each year, and capitalizing the first cost and necessary maintenance and repair work at 6%, it appeared that a pine flume, when thus capitalized, would be actually as costly as a permanent structure even two and one-half times as great in first cost. As a matter of fact, careful estimates showed that a well-built pine flume, properly supported on posts founded on masonry pedestals, would cost more than one-half as much as the permanent structure that has been built, so that the early abandonment of a flume design was fully justified.

The Reclamation Service, therefore, attempted to combine some of the advantages of flume construction with the more permanent types by working out a design in reinforced concrete, which alone promised to give the lateral stiffness necessary to resist both external and internal loadings, as well as to reduce the undercutting of the side-hill slopes to a minimum.

The most conspicuously practical difficulties in the way of masonry construction on the canal location were lack of concrete materials, water, and working space. Gravel and sand in any quantity could only be found at certain localities along the bottom of the cañon. Water for mixing and sprinkling would have to be taken from the river, many hundreds of feet below the canal location except at its upper end, and, moreover, the transportation of building materials and the conduct of building operations on the canal line would obviously be attended with much inconvenience on account of the steepness of the cañon walls and the narrowness of the ledge on which work must be done.

It was further apparent that reinforced canal lining capable of resisting the stresses to which it would be subjected and at the same time economical in the use of materials to the fullest extent could not be built in place advantageously on the canal location so as to insure the necessary excellence of work on a large scale; on the other hand, it was plain that first-class work in reinforced masonry could be executed in the bottom of the cañon at places where there was sufficient working space, and water and good concrete material could be had in abundance.

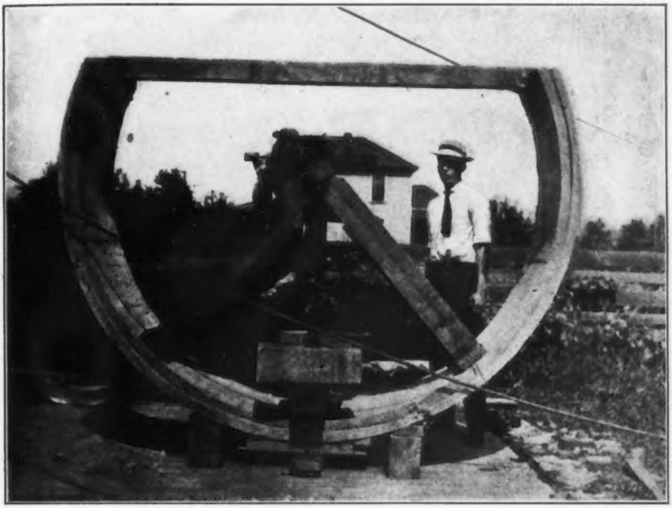


FIG. 1.—TESTING SECTION, SHOWING METHOD OF APPLYING INTERIOR PRESSURE.

FIG. 2.—TESTING SECTION NO. 4.

The idea of building the canal in separate sections of reinforced concrete, each self-contained and sufficiently rigid to permit of transportation and handling, was therefore conceived. Accordingly, arrangements were made to utilize certain flats adjoining the river as manufacturing yards where most of the conditions suitable to successful manufacture could be found and the work could be at all times inspected systematically and rigidly.

Those familiar with building pipes and conduits in concrete will realize the advantage of moulding the concrete in forms placed so that the material can always be deposited vertically and tamped, and subject to uniform conditions and rigid inspection. These conditions existed to a marked degree in the manufacturing yards, being one of the prime considerations in the adoption of the process.

It was concluded that, if the lining could be made satisfactorily in the yards, the difficulties of handling and transportation could be overcome by careful organization and the selection of suitable plant. The most serious problems to solve, in connection with this plan of construction, were the determination as to whether reinforced concrete sections or shapes such as these would permit of handling and transportation without serious injury to themselves, whether the back-filling could be done satisfactorily so that the shapes would not subsequently settle irregularly, and whether the joints between the shapes could be made in a satisfactory way.

During the spring and summer of 1906 several designs were prepared for concrete shapes, and later, experimental sections were built and tested in the grounds of the local office of the Reclamation Service at North Yakima. The test sections were made of many different shapes and sizes, two of which are shown on Plate XX. They were tested, as to their ability to stand internal stress, by a special apparatus applying internal pressures at points where the resultants of internal hydrostatic pressures with a full conduit would fall. This testing apparatus consisted of an A-frame set inside the concrete shape with each leg delivering pressures obtained by tightening up a tension rod passing midway between the struts and resisted by a yoke on the outside of the bottom of the shape. This device is shown by Figs. 1 and 2, Plate XX. The pressures were registered by a special device, and were noted carefully during the period of each test, the shape itself being at the same time subjected to a close scrutiny and the development of all cracks and changes in diameters being measured and noted carefully.

The conditions to which the shapes were subjected during this test were obviously not exactly parallel to those resulting from actual field conditions, it being impossible to duplicate by mechanical means the varied stresses under working conditions. The tests, however, were in many ways much more severe than might reasonably be expected under working conditions, and in every case the pieces were tested to failure. It was found during the experiment that the shapes possessed considerable elasticity; that hair cracks developing under pressure apparently had no permanent weakening effect, and that certain sections possessed much rigidity and strength. These experimental shapes were cast in wooden forms, and, owing to the swelling of these, the reinforced concrete cross-bars were frequently cracked at the point where they joined the main body of the shape. The test pieces were weakened to a considerable extent owing to this cause. In spite of this disadvantage, however, the tests showed that, with proper care, reinforced concrete shapes such as these could be built cheaply and handled safely.

The shape that appeared to be the most satisfactory resisted internal pressures of 3 350 lb. from each strut, which was more than twice what the hydrostatic pressure would be with the canal entirely full of water. Under this pressure it was found that the horizontal diameter increased about $\frac{3}{8}$ in., which, however, was largely recovered when the pressures were removed. During the application of pressure some hair cracks could be detected on the face of the concrete under tension, but, after the pressures were relieved, they wholly disappeared. The sections were tested for external stresses due to handling in various ways, such as being dropped on a hard floor from a height of several inches, being rolled on one side, and being dropped from greater and greater heights until they were finally broken.

From data obtained during these tests it was determined that this method of construction promised satisfactory and economical results on a large scale, and final designs for open canal and tunnel sections were prepared.

Complete plans and specifications for canal construction were made, and the work was advertised for public contract, bids being opened during November, 1906. Two alternative methods of bidding on the canal construction were offered, one being to build the lining in sections, as above described, and shown by Fig. 2; and the other being by

the older and standard method of depositing concrete lining in place in the canal as shown by Fig. 1. Only one bid was received, and that was based on the method of manufacturing and placing the concrete shapes as described previously.

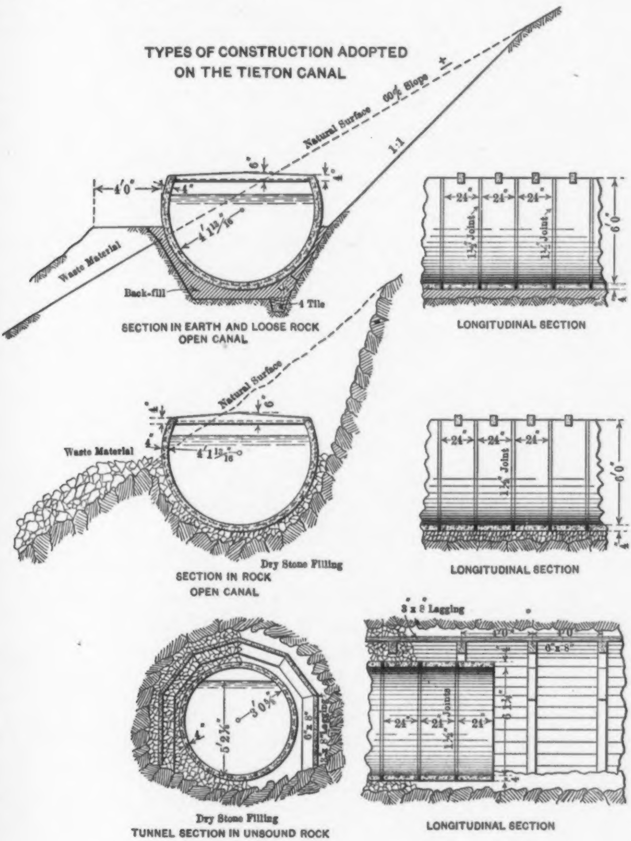


FIG. 2.

A contract for manufacturing and laying concrete shapes was awarded, and work was started during 1907. After little more than a start had been made by the contractor, the plant and work were taken over by the Reclamation Service, and the work was carried to comple-

tion in the fall of 1909, all work being done by force account under the direction of the engineers of the Service.

Fig. 2 shows the typical cross-sections of open canal work and tunnel work as constructed. The sections or shapes in which the lining was manufactured are of uniform length (measured along the canal) of 2 ft., both for open canal and tunnel work. Each shape consisted of a slab of reinforced concrete, 4 in. in thickness, moulded to the desired shape. The reinforcement consisted of $\frac{3}{8}$-in. corrugated rods placed 4 in. from center to center. Each open canal shape was stiffened by a 4 by 6-in. cross-bar, which had for reinforcement two $\frac{3}{8}$-in. corrugated rods. The tunnel shapes were completely cylindrical. The concrete in these shapes was generally composed of 1 part of cement to 10 parts of unmixed aggregates, the latter being proportioned so as to give a mixture as dense as possible. The shapes were all cast on their sides in steel moulds. The moulds were made of thin sheet-steel, riveted to steel angles, and stiffened with suitable bracing of light angle iron. The moulds for the open canal were made in four pieces, two inside and two outside. All tunnel moulds were made in six pieces, of similar construction. All parts were light, the heaviest being handled easily by two men. The method of construction may be briefly described as follows:

At points along the bottom of the cañon, level spaces, each of a few acres in extent, were selected and used as yards for manufacturing the shapes. These spaces were necessarily of small area, being practically all the space available, the cañon being generally a mere gorge. At some of these points concrete material was at hand, but at others it had to be hauled from a distance. All open canal and tunnel lining shapes were cast at these yards, the process being continued until each yard was filled, or the necessary number of shapes were cast. Whenever the yards were sufficiently large so that storage could be had to enable the first shapes cast to be cured and hardened properly, a process requiring 30 days, before the yard was entirely filled, the manufacture of new shapes and the removal of the finished product took place simultaneously, so that at one end of the yard new shapes were being made, while at the other end shapes were being loaded on cars and hauled away, this being continued until all lining appurtenant to that yard had been completed. At other points, where space was limited, a yard would be filled with shapes which would then be left

FIG. 1.—YARD FILLED WITH CANAL SHAPES.

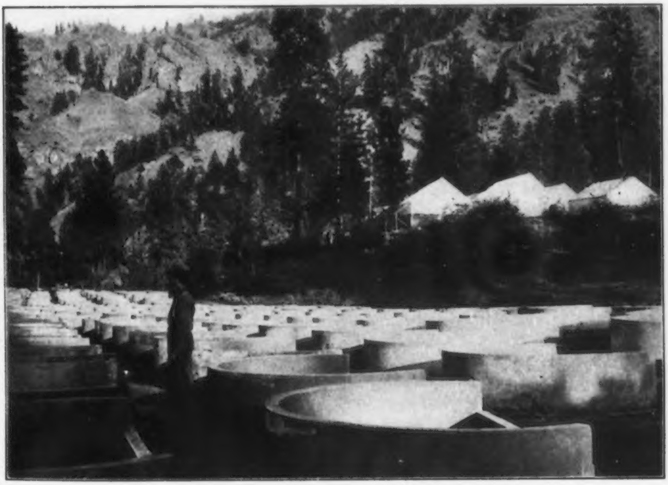


FIG. 2.—YARD FILLED WITH CANAL SHAPES.

to harden while work started at some other point. Yards filled with finished shapes are shown on Plate XXI.

All mixing was done in cubical batch mixers, each batch exactly filling a mould, the open canal shapes containing about 0.47 cu. yd., and the tunnel shapes about 0.50 cu. yd. All the aggregates were screened by rotary screens and segregated into two grades of gravel and one of sand, the coarsest gravel used passing a 2½-in. mesh. All material was obtained from the river bed or adjacent bars, passed through a crusher, and screened, the coarser fragments being returned to the crusher. A very wet mix was used.

The yards for manufacturing were first cleared of obstructions, such as large rocks, fallen logs, etc., and, if necessary, roughly leveled and staked out preparatory to placing the forms or moulds in position. In placing the moulds, the inside forms were first set up over a portable templet and bolted firmly together, so that all shapes should have exactly the same inside dimensions by being fitted to the same templet. Fig. 1, Plate XXII, shows a portable templet and the method of setting up the inside forms. The latter, when bolted together, were then laid in their correct position on the ground, being supported by small wood blocks; the outside forms were then placed in position, spaced 4 in. outside of the inner forms, and held there by wooden blocking and iron clamps. The next step was to prepare a firm and correctly moulded base on which to tamp the concrete in the moulds. This was obtained with a preparation of sand and plaster of Paris worked to the consistency of mortar and tamped to a thickness of about 1 in. in the bottom of the mould. The top of this plaster was readily brought to a smooth, even surface by metal moulding irons. The plaster of Paris quickly hardened into a tough plastic mass, which wholly closed the bottom of the mould and gave an even bed on which to ram the concrete; it also prevented the leakage of the finer portions of the concrete material.

A regular gang in each yard attended to the setting up and removal of the forms and their subsequent cleaning and transportation to other localities, also to the preparation of the plaster of Paris bases. This gang acquired much dexterity by constant repetition of the same process, which had to be performed many thousand times during the work. Frequently, keen rivalry existed between the gangs in different yards as to how many forms could be set up in place in a given time.

After being set up, all forms were carefully oiled on the surfaces with which the concrete would come in contact. After the bases had hardened sufficiently, the concrete-placing gang performed its share of the process, a batch of concrete being hauled from the mixer to each shape in turn in an ordinary bottom-dumping car, the material being dumped into a vat placed next to the form to be filled. The mixture was immediately shoveled into the mould, the steel reinforcement being placed at intervals of 4 in. as the mould was gradually filled. The reinforcement was held in place during the process with spacing bars of proper width, which were withdrawn as the concrete gradually filled the mould. The mould when filled was left for a short time for the concrete to settle, it being usually found that a settlement of about ½ in. to 1 in. would take place as the material gradually consolidated and air bubbles escaped. Before the initial set had taken place, however, the shape was finished by troweling off the top surface evenly with mortar and moulding it with a special moulding iron so as to form a depression around its upper edge for jointing purposes.

The process of setting up forms and placing concrete and steel was performed with remarkable expedition and by a comparatively small number of men, considering the large variety of special parts to be handled. The regular gang for setting up and handling the forms and preparing the bases consisted generally of one foreman and 10 men. This gang would set up generally about 80 to 100 forms per day at an average cost of a little more than 50 cents per form, or equivalent to about $2.20 per cu. yd. of concrete. The average cost of excavating, handling, crushing, and screening the concrete aggregates was about $1.50 per cu. yd. of concrete. The cost of mixing and delivering the concrete to the moulds was about 70 cents per cu. yd. The cost of placing concrete in the moulds, including the handling and placing of steel reinforcement, was about 65 cents per cu. yd. In other words, the total labor cost for the finished concrete in the moulds was about $5.05 per cu. yd. The cost of plant and supplies added about $3.20 to this figure, the latter including the cost of all steel forms, mixers, crushers, pipes, pumps, teams, and wagons used in connection with making the concrete for the open canal shapes. The total cost, therefore, for labor, supplies, and plant for this concrete was about $8.25 per cu. yd.

The concrete shapes after being cast were left undisturbed for intervals of from 24 to 36 hours before the forms were removed. During

FIG. 1.—PORTABLE TEMPLET FOR SETTING UP MOULDS.

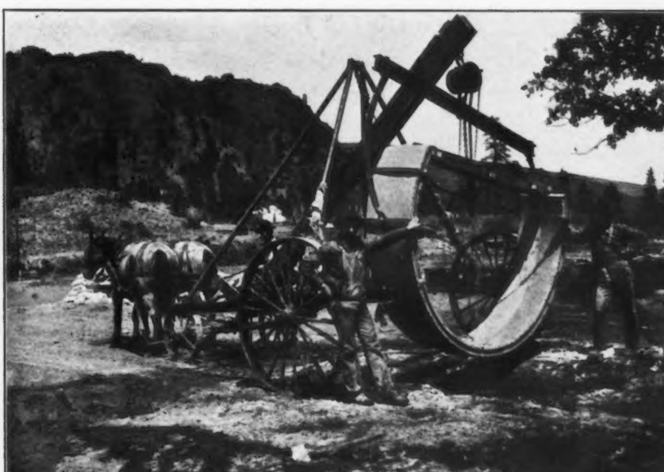


FIG. 2.—RAISING AND HAULING CANAL SHAPE IN YARD.

the colder weather this period was sometimes extended to two or three days. At these times the top and exposed surfaces of the moulds were covered with wet gunny-sacks to prevent the occurrence of sun cracks in the concrete. The moulds were then removed simply by collapsing the inside centers, after removing the interior bracing, and then peeling off the outside forms, after unbolting them. The reinforced cross-bars in the open canal shapes were left with their bottom form, which consisted of a 1½-in. pine plank, in place, supported in its middle by a small wooden prop. The forms were stripped by a trained gang in a very systematic and expeditious way. Each part of the removed form was carefully laid aside for reassembling, and afterward cleaned, oiled, repaired as required, and transported to a fresh location to be used again.

The concrete when stripped invariably had clean, smooth surfaces with sharp edges and good color. Immediately after stripping, the concrete was covered with gunny-sacks or canvas and sprinkled continuously for a period of about 10 days in the warm weather. For this purpose a complete system of piping, hose, and pumps had been established in each yard, and the water was delivered from the nozzles under a good pressure, thus making the sprinkling effective. In the larger yards as many as two or three men were continuously sprinkling the concrete; this proved to be one of the most difficult parts of the process to execute in a satisfactory way, owing to the large areas over which the yards extended. In spite of all precautions and vigilance, it appeared that this portion of the work was perhaps executed in the least satisfactory way. From time to time, however, tests were made of the comparative qualities of the concrete cured in the yards, and apparently it was not appreciably inferior in strength or toughness to samples of concrete kept continually immersed in water.

The cost of wetting and finishing the concrete for open canal shapes was about $1.00 per cu. yd., thus bringing the cost of concrete up to $9.25 per cu. yd. for labor, plant, and supplies for the completed shape, or about $4.10 for each shape measuring 2 ft. along the canal line, or equivalent to a little more than $2.00 per lin. ft. of canal lining for the open canal.

About 35 lb. of steel was used for each shape, and about ½ bbl. of cement, each costing about $2.10 and $1.50, respectively; so that the final cost of the concrete in the open canal shapes when completed and lying in the yard ready for transportation to the canal, including the

cost of cement and steel, was about $8.00 per shape, or $4.00 per ft. of canal lining, or, if reduced to a yardage basis, equal to about $17.00 per cu. yd.

The costs of tunnel lining were somewhat higher than the above, largely due to the fact that the plant charges for tunnel were more than for open canal work, as there was a smaller quantity of tunnel lining to build, so that the distributed plant costs were higher. The final cost of labor, plant, and supplies in 1908 for tunnel lining was about $11.50 per cu. yd. of concrete. The gross cost, including cement and steel, was about $19.00 per cu. yd., or about $9.50 per individual shape 2 ft. long, or $4.75 per lin. ft. of tunnel lining.

The foregoing figures for the costs were obtained about the end of 1908, after about one-half the work was completed and the more serious initial difficulties of construction had been overcome. Administration and engineering charges are included, averaging in amount about 13%, inclusive of the cost of building a wagon road, described later.

The shapes were permitted to lie in the yards for a period of not less than 30 days, after which they were raised from their beds and hauled to the point where they were loaded on special cars for delivery to the canal. The process of raising and hauling is shown by Fig. 2, Plate XXII.

Before leaving the yard, all sand and plaster of Paris that might be still adhering to the bottom edges of the shapes was removed. This required only a few moments' application of a wire brush. The shape was then lifted with a differential block and loaded on a special steel car shown by Fig. 1, Plate XXIII. The loaded car was then pushed on a siding ready for transportation to the canal.

From each yard inclined hoists driven by electric motors, or cableways similarly operated, were used to deliver the loaded shapes to the canal location. Sometimes as many as two or three cars were hoisted at a time, depending on the length and steepness of the incline. The loaded cars when delivered at the canal location were made up into trains of four or five cars and hauled by horse along a temporary track laid in the canal bed to the point where laying operations were in progress. Fig. 1, Plate XXIII, shows a train of cars containing open canal shapes being hauled along the canal. Sidings at suitable intervals permitted the passage of empty return cars. Transportation was thus reduced to a simple and economical process, the labor cost of

FIG. 1.—TRAIN OF SPECIAL CARS LOADED WITH CANAL SHAPES.

FIG. 2.—SPECIAL DEVICE FOR PLACING SHAPES IN CANAL BED.

transporting and handling the shapes from the yard to the canal and hauling along the canal being about 33 cents per ft. of lining.

The loaded train of cars was stopped at the siding nearest to the point where shape-laying was in progress, each full car as required being individually run forward to be unloaded; the empty cars were shunted to the main track for final return to the yard.

A special device was used for unloading the shapes from the cars, and handling and placing them in final position in the canal. This device, shown by Fig. 2, Plate XIII, consisted essentially of a braced frame of 3-in. iron pipe supporting an overhead I-beam running longitudinally to the canal, directly over the spot where the cars delivered their loads. On the I-beam there was a small trolley carrying a differential block. From the differential block was suspended the newly delivered concrete shape, and the trolley permitted longitudinal adjustment. Lateral adjustment was obtained by a device permitting the overhead I-beam to be swung from one side of the canal to the other as required. The delivered shape was suspended from the differential block by a yoke fitting to the inside of the shape.

The shape when delivered was first swung from the car by the differential pulley, the empty car being immediately run back. The shape, hanging from the block and overhead trolley, was then run along the I-beam to its correct position in the trench, all lines and grades having been taken in advance so that final adjustment could be made without the loss of more than a few moments. Various ingenious devices were elaborated by the trained crews who performed this laying work, so that the shape when once adjusted in position was firmly held by clamps and blocks prior to the deposition of the back-filling.

The process of delivering and setting these shapes was a very interesting one, the gangs being thoroughly drilled and each man an expert in his line of work. As each open shape weighed about 1800 lb., engineers familiar with the placing of heavy masses will realize the difficulty of adjusting them accurately and speedily. Adjustment for each shape had to be made for line and level, both laterally and longitudinally. When adjusted in position and carefully blocked, the shape was at once back-filled, the space between the bottom of the concrete shape and the canal bed being from 4 to 6 in. The back-filling material was shoveled into this space from the end, each shovelful being tamped with long iron rammers to

such hardness that the shape generally began to be raised from its bed by the pressure of the rammed material before the ramming was discontinued. A great deal of attention was given to the thorough tamping of the back-filling directly under the shape so that there should be no danger of subsequent settlement. The back-filling for a width of about 6 ft. under the shapes, therefore, was watched very carefully, and only selected material was used for this purpose, all material of a loamy nature being excluded.

The back-filling around the sides of the shapes was not done with the extreme care used in the other portions, the material being shoveled in from the top and rammed every foot or two in depth by hand rammers. A space about 1½ in. in width, between the concrete shapes was left for the jointing, to be performed subsequently.

The laying gang, consisting of an inspector, a foreman, and eight laborers, laid on an average from forty to fifty shapes per day in open canal work, or a total of from 80 to 100 ft. of canal lining. The cost of labor in handling and placing the shapes was about 47 cents per lin. ft. of lining, this price including the cost of all back-filling.

On sharp curves shapes moulded a little narrower on one side than on the other were inserted, but when the curves were of large radius no specially moulded shapes were used, the curve being entirely taken up by the joints.

The jointing, the last process, was carried on as far as possible during the early mornings and the cooler weather so that the concrete would be at the lowest possible temperature at the time the joints were made. During this process the portion of the canal being jointed was covered with canvas to exclude the direct rays of the sun and to keep the temperature low, the canvas being generally kept wet so that the temperature would be lowered by evaporation.

The joints were made of concrete of a fine aggregate, the stones passing a ½-in. mesh. The joint was well filled, but before the concrete had acquired its set, the surface of the joint in the interior of the canal was scraped off and a finish coat of mortar was troweled on, so that the finished surface of the joint was exactly flush with the surfaces of the adjacent shapes. The width of the joints permitted any small irregularity, due to the placing of the shapes or to the dimensions of the shapes themselves, to be taken up without any jog in the interior of the canal. The result of this jointing

work has been in general very satisfactory, the interior of the canal having a remarkably smooth and even surface.

The joints after completion were kept well wet until the concrete had hardened, and whenever practicable the canal after being jointed was kept full of water, so that the joints were hardened under the best conditions.

Up to the end of 1908 the average cost of placing about 13 000 ft. of open canal shapes, including removal from the yards, transporting, placing, and back-filling in the trench, was about $1.30 per lin. ft. of canal lining, or $2.60 per shape. The cost of jointing about 5 000 ft. of lining was found to average about $1.00 per joint, or 50 cents per ft. The gross cost, therefore, of the concrete lining in place, including all plant and general charges, engineering, and administration, but excluding any canal excavation or preparation of the canal bed, was about $5.80 per ft. A finished portion of the open canal is shown by Fig. 1, Plate XXIV.

All long tunnels on the canal except one (the Trail Creek Tunnel) were lined with reinforced concrete shapes built in rings 2 ft. in length. There were three of these tunnels having an aggregate length of about 8 000 ft. All were driven through lavas and basaltic formations, and, for the greater part of their length, timbering was required, even for temporary support. The tunnel lining was cast in yards in the same manner as the open canal lining, and the shapes were finally delivered in the tunnel on small cars. These cars were specially designed for lightness and compactness, so that the empties could be readily lifted from the track and stacked temporarily in the tunnel pending their return to the yards, without interference with the delivery of the loaded cars.

As in the case of the open canal shapes, special mechanical devices were used for handling the completed shapes at the point where laying operations were in progress, and thereafter holding them in place during back-filling. The device consisted essentially of a steel I-beam supported on rollers and braced to the bottom and sides of the completed work. The delivered shape was supported by a yoke fitting inside of it and running on a trolley along the I-beam, by which it could be readily run into position. The supporting I-beam permitted all vertical and lateral adjustment and held the shape in position during the process of back-filling in spite of its great weight and the cramped quarters in which the men worked.

The back-filling was rammed into position as soon as each shape was accurately adjusted. In cases where there were large cavities over the roof or in the haunches, requiring excessive quantities of back-filling, pine logs and blocking were used as fillers to a considerable extent. All back-filling on the bottom and sides, however, was made with fragments of hard rock.

The jointing was done subsequently in the manner described for the open canal work, the devices used being, of course, modified to suit the different conditions of the tunnel work. By constant drilling and practice the men were able to lay the shapes in the tunnel in a very expeditious and satisfactory manner. Alignment and grades were always scrupulously kept, and the back-filling could readily be made subject to constant and vigilant inspection. It may be remarked here that this method of lining for small tunnels has proved very successful, both from economic and qualitative standpoints.

The tunnel which was not lined by this method was driven through about 3 200 ft. of very hard and firm basalt, and, as there seemed to be no necessity for a permanent arch for the roof, it was decided to omit it, in general, and build concrete lining in place by the usual methods. It was found, however, that the actual cost of lining and back-filling, which in this case included only the side-walls and invert, exceeded the cost of the complete circular lining by the shape method as previously described. This was due principally to the excessive quantities of concrete required to fill holes and cavities in the sides caused by irregularities in blasting the tunnel. The method of tunnel lining by shapes is advantageous inasmuch as the costly masonry lining is kept to a minimum impossible to attain with the older method. The principal advantage of the method of building lining by shapes, however, is that first-class work can be assured with greater certainty than by the standard method, all masonry being built in the open, and subject to rigid inspection; the placing and back-filling are also carried out under much better control than is possible under ordinary conditions of tunnel work. The experience derived from lining the tunnels for the Tieton Canal has demonstrated that this method of tunnel lining can be readily used wherever tunnels of moderate dimensions require treatment.

The cost of tunnel lining in the yard at the end of 1908 was about $4.75 per ft. of completed shapes. The cost of transporting, laying, back-filling, and jointing tunnel shapes was found to approximate

FIG. 1.—A FINISHED PORTION OF OPEN CANAL.

FIG. 2.—PART OF ALIGNMENT OF CANAL.

$3.60 per lin. ft., so that the completed tunnel lining in place, including all plant and operation charges, but not including any excavation or timbering, was approximately $8.35 per lin. ft.

The other principal feature of canal construction was the excavation for the open canals and tunnels. All tunnels, except one short one, were built by force account, that is, by a force organized and operated by the engineers of the Reclamation Service. The aggregate length of tunnels thus built was about 10 000 ft. There were no noteworthy features connected with this tunnel work, except that costs were generally kept down to a satisfactory figure, in spite of the difficult nature of the material encountered, and the entire work was completed without any serious mishap.

The two lower tunnels, called the Tieton and North Fork Tunnels, respectively 2 900 and 3 000 ft. in length, were driven by compressed-air drills of the ordinary type, the compressor being located in the bottom of the cañon, midway between the tunnels. Tunnel operations were generally carried out in two 8-hour shifts per day, although the arrangements of the shifts was frequently altered to meet changing conditions. The cost of driving these two tunnels, including all material for plant, up to the end of 1908, when the greater portions were completed, was about $19.00 per ft. It may be of interest to know that these figures represent actual costs of tunnel work during a period when labor was abnormally high and difficult to obtain and hold, the work being also at a remote location where all material and supplies had to be hauled from a considerable distance.

The following are the details of the cost of tunnel driving for the North Fork and Tieton Tunnels:

	Per linear foot.
Labor in tunnel	$8.00
Explosives	1.50
Supplies	0.50
Power-plant operation	1.10
Blacksmith shop	0.75
Timbering	2.50
Plant charges	5.00
Total	$19.35

The above costs include engineering and administrative charges. The inside dimensions of these tunnels, as excavated in the rock, were approximately 8 by 8 ft.

The third long tunnel, the Trail Creek Tunnel, was driven for almost its entire length through an unusually hard blue basalt. The driving was effected at first by electric drills operated by three-phase, 60-cycle, 220-volt alternating current. As the work progressed, continual trouble was caused by breakage of parts of these drills, the springs operating the rebound being particularly susceptible to injury. Duplicate parts could only be obtained after much delay. In addition, there was much difficulty on account of labor, it being found practically impossible to obtain drillmen skilled in the use of electric drills. Ordinary drillmen would generally refuse to use the apparatus, or, if persuaded to make a trial, would obviously use it in an unsympathetic and ineffective way. Careful study, however, of the effectiveness of the electric drills, even when skillfully handled, showed that in very hard rock they were uneconomical, their penetrative power being low. Eventually, Temple-Ingersoll drills were substituted, and the work was completed with them. These drills are practically air drills driven by an electrically-operated air pump on a small truck. This apparatus was found to be much more effective than the electric drills for which they had been substituted, the blows being much more forcible and the penetration correspondingly more economical. This apparatus, moreover, was found to be far less subject to injury than the electric drills.

The cost of driving the Trail Creek Tunnel proved to be much higher than that of the other two tunnels, the corresponding figures for tunnel excavation being about $20 per lin. ft., in spite of the fact that little or no timbering was required.

Excavation in the open canal, that is, the preparation of a bed for the concrete shapes, was also attended with considerable difficulty because of the location of the canal, the steep slopes, and the numerous side gullies and gorges which broke the continuity of the side-hills and required special treatment. The line was located so as to reduce the excavation to a minimum and also so that there should be the minimum disturbance of the natural slopes of the hillside. The natural slopes, however, were frequently so steep that a 1½ to 1 slope on the upper side of the canal excavation would only intersect them at a considerable distance above the canal line, so that, even with the shallow cut required for this type of construction, a large quantity of material had to be removed.

FIG. 1.—DRY RUBBLE EMBANKMENT AT CROSSING OF GULLY.

FIG. 2.—SAND-GATE AT UPPER END OF LINED CANAL.

Practically all excavation was by hand, the steepness of the hillside not permitting the use of animals or mechanical methods. Much of the excavation was in rock. The average cost of excavation per cubic yard up to the end of 1908 was about 65 cents, inclusive of both earth and rock. It is probable that about 30% of the entire work was in solid or loose rock. Wherever the canal location was in earth, a 4-in. drain tile was laid along the bottom of the trench on the side toward the hill, outlets for the drain being built at intervals of from 300 to 500 ft. This drain was for the purpose of taking care of natural ground-water, or seepage water from the canal, and preventing its accumulation and consequent tendency to soften the bed of the reinforced lining.

All deep gullies on the line of the canal were crossed on dry rubble embankments, and, where necessary, masonry culverts were built at the bottom of these. Fig. 1, Plate XXV, shows the method of crossing one of these gullies on a rubble embankment. At certain points large jutting shoulders of rock necessitated short tunnels, 100 or 200 ft. in length, and in such cases the tunnels were driven of sufficiently large section to permit of laying open canal shapes continuously through them, thus making no break in the continuity of the open canal.

The diversion dam on the Tieton River is a low overflow weir of concrete, heavily protected with rock paving and founded on a rock-filled timber crib. The head-gates are set in masonry built into the ledge. All this work is particularly solid and permanent, but does not need special description in this paper.

Immediately below the head-gates, the canal is in open unlined earth cut for about 1 000 ft., being practically in the bottom of the cañon. The material is heavy gravel and cobbles, and the canal is well protected from the river. At the lower end of this unlined channel there is a special structure intended to exclude sand from the lined canal. At this point the water flows over a low masonry lip, beneath which are small channels leading directly into the river through lines of vitrified pipe. Sand being carried in suspension along the bottom of the canal, will at this point pass under the lip and be returned to the river. Fig. 2, Plate XXV, shows this structure (called the sand-gate) and also the upper end of the lined canal, which, from this point, is lined with reinforced concrete for about 12 miles. The transition of open canal to tunnel at one point is shown by Fig. 1, Plate XXVI.

The gradient of the open canal is 0.00165, or 8.71 ft. per mile. The inside diameter of the reinforced lining is 8 ft. 3⅝ in., and the distance from the bottom of the cross-bar to the invert is 6 ft.

The canal at its capacity is designed to flow 5 ft. 3 in. in depth, leaving a clearance of 9 in. under the cross-bars. The area of cross-section of the flowing stream, therefore, is 36.01 sq. ft. It was estimated that the lining would have a coefficient of roughness of 0.012 in Kutter's formula, and the resulting velocity would be 9.05 ft. per sec., with a discharge of 326 sec-ft. The canal being intended to carry 300 sec-ft., it was considered that the additional allowance of 26 sec-ft. was justifiable as a margin of safety to provide for possible subsequent increase in frictional resistance due to organic growth within the conduit, or perhaps to roughening of the interior surface.

The gradient of the tunnels is 0.0045, or 23.9 ft. per mile. The finished inside of the tunnels, excepting the Trail Creek Tunnel, is circular in shape, with a diameter of 6 ft. 1½ in. The depth of flowing water in the tunnel at the canal capacity was estimated at 5 ft. 3 in., leaving a maximum clearance of about 10 in. The sectional area of the flowing stream was estimated at 26.55 sq. ft., the coefficient of roughness being estimated at the same figure as considered for the open canal. The estimated velocity was 12.65 ft. per sec., with a discharge of 336 sec-ft., it being intended to leave a somewhat higher margin of safety than in the case of the open canal.

The alignment of the open canal had frequently to be very tortuous on account of the topography of the side hills, as shown by Fig. 2, Plate XXIV. The maximum curves had a radius of 50 ft., and at certain points it was necessary to have reversals, even with this extreme curvature. The tunnels were built without curvature. An actual test of the hydraulic efficiency of the canal was awaited with much interest, some doubt being entertained as to whether the completed canal would justify anticipations as to its delivery. Measurements of flow made in a concrete-lined canal in Oregon early in 1909 appeared to indicate that heavy losses of head due to sharp curvature might be expected, and, moreover, the retarding effect of the innumerable transverse joints between the concrete shapes in the Tieton Canal was an entirely unknown factor. The canal was completed in the fall of 1909, but the upper few miles were subjected to hydraulic test during July of the same year.

FIG. 1.—TRANSITION FROM OPEN CANAL TO TUNNEL.

FIG. 2.—EMERGENCY WASTEWAY.

During this test the quantities flowing were measured in the unlined section of the canal between the head-works and the sand-gates, where the velocity is low, measurement being taken by careful current meter gaugings. The maximum quantity measured was 274 sec-ft., the water being wasted at one of the emergency wasteways about 2½ miles below the sand-gates, shown by Fig. 2, Plate XXVI. This portion of the lined canal was the first to be built, and the grades and alignment were not as well kept as in the portions built later. The first reinforced shapes that were manufactured were also placed in this part of the work, and in many respects these shapes were inferior in quality to those made later, as experience and skill in the operative force developed. Therefore it was reasonable to expect that the hydraulic qualities of this part of the canal might be somewhat inferior to those of the other portions.

During the tests the quantity of water flowing was measured continuously below the head-gates, and measurements down to the surface of the flowing water were taken at various points in the canal. There was much difficulty in taking the latter measurements with any accuracy owing to high velocity and erratic wave action. Precise measurements of this kind, however, have little significance, save to establish the mean depth of the flowing water. The average of a number of readings showed that, with 274 sec-ft. of water flowing, the mean depth in the lined canal was 4 ft. 7 in., or 8 in. less than the estimated depth at full capacity. This shows that the equivalent of Kutter's n would be almost exactly 0.012, which is the estimated figure.

The following observations are quoted from the statement of J. S. Conway, Assoc. M. Am. Soc. C. E., Engineer in Charge:

"The flow through the lined section was replete with anomalies, and did not seem to obey any of the common hydraulic laws. There were a number of points where the water was heaped up and thrown into considerable turmoil without any apparent cause. These points * * * occurred at regular intervals, regardless of curves or tangents, and, in fact, were somewhat more noticeable on long tangents than in other places. In addition, there were traveling surges of water which worked their way slowly down the canal, causing irregularity of about 6 in. in depth from a given point. There were also quickly changing high and low points varying between a few tenths (in height) which seemed to travel with the water. There were places where the depth was not over

3 ft. for a stretch of 50 to 75 ft., and other places of similar length where the depth was 5 ft. or over. With the exception of the extreme case just below the sand-box (at the intake of the lined section) the cross-bars had a minimum clearance of 8 or 9 in. While there was practically no smoothness of water surface, generally speaking, the water went onto all curves easily, very often heaped on the inside instead of the outside, as theory requires, and usually went off the curves onto tangents with disturbance. * * * The transporting effect of this velocity was remarkable. A 25-lb. rock fastened on a wire started straight down stream and a 100-lb. rock fastened in the same manner took two men to pull it back and out. An attempt to draw out a pail full of water nearly lost the bucket."

On October 25th, 1909, the writer visited the completed canal at a time when a test was being made of the upper 4 miles. Unfortunately, it was impossible to divert more than about 160 sec-ft. from the river, the water in the lined section flowing 3.2 ft. deep. The characteristics of the larger flow commented on by Mr. Conway on July 4th were noted, however, as existing to a considerable extent. The canal had evidently been constructed with a too rigorous contraction at its entrance at the sand-gates, and at certain points there were noted variations in velocity and depth not readily explainable by alignment or quality of work. It would almost appear that, in long channels of uniform cross-section and slope, such as this, where high velocities obtain, there is a constant tendency of the mass of flowing water to lose and recover the equilibrium of the hydraulic gradient and velocity due to the forces of gravity, and the retarding effect of frictional resistance is overcome or adjusted in part by local and fixed irregularities of flow, and sometimes in traveling surges or waves such as may always be observed in chutes or wasteways where velocities approach that of free falling bodies. In spite of these vagaries of flow, it has been demonstrated that the conduit can be depended on for its full calculated discharge, and possibly even more.

The water introduced was at a temperature little exceeding that of freezing, and the contraction of the masonry lining due to low temperature was noted at a number of joints between the shapes, generally in hair cracks of no appreciable importance, but sometimes in cracks of as much as $\frac{1}{32}$ in., which developed sensible leakage. Many of these cracks had been caulked, and it was evident that reasonably careful treatment would make the canal practically tight. The upper few

miles of the conduit tested at this time had been built for more than a year, and had withstood successfully the test of a severe winter. No damage due to heaving by frost was noticed. The principal defects, other than the temperature cracks above noted, were that at a number of points the surface of the concrete was pitted or roughened. Apparently this was due to the breaking away of small patches of plastering which had been applied at defective spots in the shapes when the forms were first removed. This plastering, fortunately, was seldom used, so that serious trouble from this cause need not be anticipated.

In connection with the satisfactory coefficient of flow developed in this conduit, it is interesting to make a comparison with a conduit of almost similar shape on the Umatilla Project, in Oregon. This conduit is 9 ft. in diameter, and is intended to carry 300 sec-ft., or the same quantity as the Tieton Canal. The Umatilla Canal has a reverse curvature of 90°, with curves of 50 ft. radius, which is comparable with the most extreme curvature of the Tieton Canal. The Umatilla Canal was finished in 1907, being built of plain concrete deposited in place in the usual way. The forms used in construction were in 10-ft. panels measured lengthwise of the canal, and the lining was placed in sections of that length, with a complete transverse joint at the end of each section to allow for temperature contraction. The forms were well built, and the masonry was placed with much care and under vigilant inspection so as to insure good workmanship and high hydraulic properties for the channel.

The grades were well kept, and the curves were regular and smooth, although the curves as built actually consisted of a series of 10-ft. tangents, as is usually the case in construction of this type. A very careful test was made during 1909, the surface of the flowing water being measured by a special apparatus which practically eliminated wave effect as a disturbing factor. The quantities were gauged with a current meter.

It was found that, with velocities of 7.2 ft. per sec., the coefficient of discharge in the Chezy formula was about 130, this corresponding with $n = 0.014$ in Kutter's formula.

Both these canals being new and clean, the difference between their deliveries is worthy of special note. The only explanation offered is that the concrete lining of the Tieton Canal, being cast in smooth and well-oiled metal moulds, has a surface much superior to that of the

Umatilla Canal, which was laid against ordinary dressed lumber forms.

Apparently, little disadvantage, from a hydraulic standpoint, has resulted from the innumerable transverse joints in the Tieton Canal, and the method of construction has been more favorable to hydraulic effectiveness on curves than the standard construction used at Umatilla. On the latter it was noticed that, on curves of the same radius, the disturbance was much greater than on the Tieton Canal. Practically, the only apparent advantage the latter has in its hydraulic surface, other than the smoothness due to the metal forms, is that the curves are worked out in 2-ft. tangents, while on the Umatilla Canal they are in 10-ft. tangents.

The physical difficulties attending the construction of the Tieton Canal were considerable. The cañon was practically inaccessible before work was commenced, except at its lower extremity, and by trails meandering from side to side, sometimes at heights of 800 or 900 ft. above the stream bed and sometimes necessitating dangerous fords.

To make preliminary surveys, the engineers had to establish camps at remote points, where the delivery of the necessities of life was attended with much difficulty.

One of the first steps after completing the surveys was to build a wagon road the entire length of the canal along the bottom of the cañon. This work had been almost completed in the fall of 1906 when a heavy flood practically obliterated all that had been accomplished. Several bridges which had hardly been used were swept away, and the bottom lands were altered, eroded, and heaped up with débris to such an extent that the topography could hardly be recognized. After this flood had subsided, however, operations were immediately resumed, bridges were rebuilt, and the road was completed early in 1907.

The Reclamation Service at once proceeded to develop water-power in order to drive the tunnels, advantage being taken of a steep fall in the river to build a power canal giving at its lower extremity a static head of about 30 ft. The turbine installation developed about 350 h.p., the turbine being belt-connected with a two-stage air compressor and a generator for lighting and power purposes.

All this apparatus was successfully installed and housed toward the end of 1907. Substantial camps were also built at suitable points along the cañon. Another hydro-electric installation was made near the upper

end of the canal for operating the mixers and crushers in the various manufacturing yards, and also for hoisting and delivering material and shapes to the canal location. Altogether, about 600 h.p. was developed at two power plants, most of which was transformed, transmitted, and used at distances for construction and lighting purposes.

At the main power station a machine and blacksmith shop was established where all repair work was done and all steel forms, special mechanical devices, and even some rolling stock were manufactured or fitted. Machine drills, lathes, rolls, drill sharpeners and other equipment were set up at this point, the motive power being compressed air. This establishment assumed quite extensive proportions as the work developed, and was the scene of much activity throughout. It should be remembered that operations in so remote a locality necessitated field execution of practically all repair and renewal work, much of which under other conditions would be sent to distant shops.

Time and difficulties of transportation, however, did not permit of much dependence on outside help, and, except in case of breakage or loss of special machinery parts or fittings, practically everything was done in the cañon.

The working season in this country is comparatively short, except for tunnel work. Operations in the open can seldom be carried on before the end of April, especially in connection with masonry work, the snow lingering very late, being sheltered by the depth of the cañon and the forest growth. Roads are usually impassable in the early spring. The building of concrete shapes had also to be stopped by the middle of October, work of this type being particularly susceptible to injury by frost. On one occasion a batch of some 200 shapes manufactured during the end of October and beginning of November, 1907, was injured to such an extent by freezing that most of them had to be destroyed.

Labor frequently proved very difficult to obtain, and more especially during 1907. Wages for common labor varied from $2 to $2.50 per day, tunnel drill men from $3 to $3.75, the working day being 8 hours. It was noted that the effectiveness of labor invariably proved to be in inverse ratio to the rate of wages. The laborers chiefly consisted of so-called "white men," being a cosmopolitan collection of native Americans, Scandinavians, and Germans, with a few English

The higher classes of labor, such as machinists, sub-foremen, and the like, were practically all native Americans.

It is believed by the writer that construction of this type has not been used elsewhere on any large scale, if at all. It has proved a successful method of building, and may be recommended for adoption elsewhere wherever conditions are such as to warrant such action. It should be remembered, however, that this type of work is particularly exacting on the organization and personnel, probably requiring more careful supervision and control than the standard methods usually adopted.

The engineers in local charge at the commencement of work were Joseph Jacobs, M. Am. Soc. C. E., District Engineer, and E. McCulloh, M. Am. Soc. C. E., Resident Engineer, both acting under the direction of D. C. Henny, M. Am. Soc. C. E., Supervising Engineer, and the writer. The organization of the work, however, was mainly built up under the local direction of Mr. C. H. Swigart, then Project Engineer, aided by an able corps of assistants. Much of the success of the work is due to the skill and ingenuity of Mr. Maney, the Superintendent, and Mr. Cronholm, Master Mechanic. The writer was associated with the work until the beginning of 1909, after which it was continued and completed under the direction of Mr. C. H. Swigart as Supervising Engineer and Mr. J. S. Conway, Engineer. All operations were under the general direction of F. H. Newell, M. Am. Soc. C. E., Director, and A. P. Davis, M. Am. Soc. C. E., Chief Engineer, of the Reclamation Service.

DISCUSSION

Horace W. Sheley, Assoc. M. Am. Soc. C. E. (by letter).—The subject of the loss of carrying capacity of a canal, due to algæ, or "moss," is increasingly important, owing to the growing use of concrete linings, which are expected to give low coefficients of friction and consequent high velocity. This expectation is not realized when the growth of algæ is excessive. The writer has in mind one concrete-lined channel which, since algæ have grown in it, carries only 400 sec-ft., at a certain stage, as compared with a clean-channel flow of Mr. Sheley.

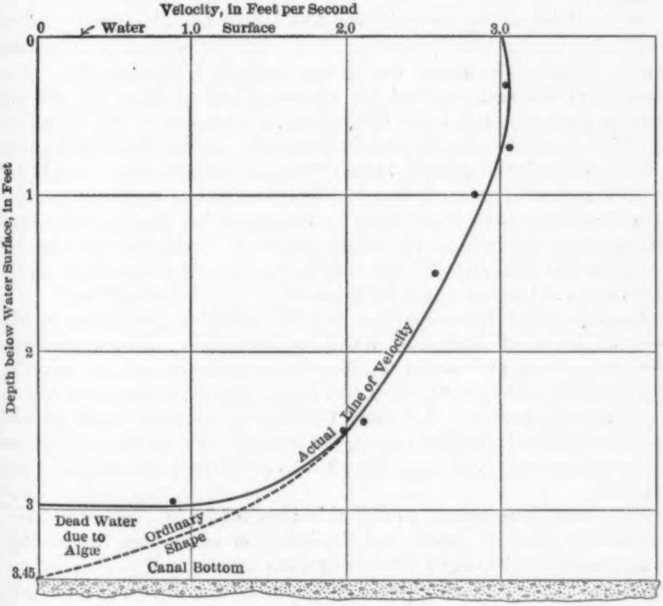


Fig. 3.

about 660 sec-ft., a loss of 40 per cent. The vertical velocity curve at the section of maximum velocity, in Fig. 3, shows that algæ are the cause of still water in the bottom half-foot of the channel, and that they decrease the velocity above, owing to the surging and cross-currents which they cause. As this canal was lined with concrete at great expense, in order to increase the capacity to a certain necessary quantity, the loss is a serious matter.

Mr. Sheley. In one of the earliest water supply papers of the United States Geological Survey, the Honorable Samuel Fortier states that algæ cause losses in carrying capacity altogether disproportionate to the area of the cross-section of the channel occupied by them.

In the case cited, the canal is so large that it would be difficult to scrape off the algæ without drawing off the water for some days; therefore, scraping would be a costly solution of the problem, and legally inexpedient. Further, algæ often reappear shortly after having been scraped off, so that many treatments might be necessary in a season. Therefore a solution of the question, which would not involve stoppage of the flow of the canal during the irrigation season, would be timely.

Blue vitriol, or copper sulphate, has been used with great success to kill algæ in municipal reservoirs, and might be applied to irrigation canals. Messrs. George T. Moore and Karl F. Kellerman state* the quantity of the salt required for various kinds of algæ, but do not mention the genus said to be *Cladophora,* a long-fibered variety, which probably causes the most trouble in irrigation canals. The *Cladophora* is said to be closely related to the *Conferva Bombycinum* which requires 1 part of copper sulphate to 1 000 000 parts of water. However, since it appears, from a list given by these authors, that in estimating the necessary proportion of copper sulphate, little reliance can be placed on the similarity of the plants, less copper sulphate or much more than 1 : 1 000 000 might be required for the desired effect.

Assuming that the proportion is 1 to 1 000 000, 5.4 lb. per sec-ft. every 24 hours of treatment would be necessary. Copper sulphate sells wholesale at present for $4 per cwt., so that the cost for the salt would be 2.16 cents per sec-ft. for 24 hours, exclusive of labor charges. Assuming the necessity for three treatments, with the total of five days, during the irrigation season, the cost for the sulphate would be 10.8 cents per sec-ft., or, say, from 0.10 to 0.15 cent per acre of land irrigated.

The strength necessary to kill this alga might be much greater—even twenty times as great—and the inflow of moss from the feeding stream would tend to start the new growth more rapidly in an irrigation canal than in a municipal reservoir; but it is likely that only occasional treatments would be necessary.

The writer does not know what effect copper sulphate would have on crops grown by irrigation, but it seems probable that the copper would be precipitated out of solution, as a hydrated oxide or basic salt, in the laterals before reaching the crops.

If treatment with copper sulphate proves impractical, either on account of the expense or the injury to crops, another method, which has occurred to the writer, might prove feasible. This method is

* Bulletin No. 64. Bureau of Plant Industry, U. S. Dept. of Agriculture.

Mr. Sheley.

based on the well-known fact that algæ are lovers of light, and must have it in order to grow well. For example, in the concrete-lined canal of the Arizona Power Company, it was found that they grew only in the open canals and not in the tunnels, though the velocity was about the same in each.

Therefore, anything tending to diminish the light would decrease the growth of algæ, and it is likely that it would be materially decreased if the concrete-lined section of a canal were painted a dull black with a thin coat of asphalt, tar, elaterite, or some other black, light-absorbing substance; for it has been observed that algæ grow in profusion on white objects and to a much less extent on dark ones. No ordinary stream velocity stops the growth, but they do not thrive in water carrying much silt. They grow quite freely even in rather cold waters.

Mr. Dunham.

H. F. Dunham, M. Am. Soc. C. E. (by letter).—This paper could have been made more interesting by further discussion of the conditions and principles which determined the section adopted for the open canal. Why have an open canal? Fig. 1, Plate XXIV, seems to show that it is the intention to cover the openings at some future time.

Several of the plates show the general character of the country, and the steep slopes in the earth and rock. In such districts and in a climate with so much frost, fragments of heavy material may be dislodged from the slopes. Sharp edges and corners are more likely to be injured than rounded and covered surfaces of concrete. Expansion would be more nearly equal if the section were covered, and the evaporation would be less; so would the chance of obstruction by foreign substances, ice, live stock, or large game.

Would not a section made thin but continuous at the crown be of greater capacity per unit of cost, and offer greater resistance to outside thrust? There may be some controlling features, which make it clear to those who know the conditions, but those who are not familiar with the conditions, look to the paper for information.

The irregular flow of water and the bad hydraulic behavior may be due to many causes which become cumulative in their effects. When a problem includes too many such causes a new law is sometimes introduced to afford full explanation. In this instance, however, reference might be made to Spencer's Law of Rhythm.

Mr. Hopson.

E. G. Hopson, M. Am. Soc. C. E. (by letter).—In reference to the decrease in carrying capacity of concrete conduits on account of algæ growth, Mr. Sheley suggests that some advantage might be expected by darkening the interiors of open channels. The writer has observed that the flow in covered masonry aqueducts is similarly impaired by the same cause, and therefore he thinks that little or no advantage might be expected by enclosing the Tieton Canal. Careful and repeated gaugings of the Wachusett, Sudbury, and Cochituate Aqueducts, in Boston,

Mr. Hopson. and the Croton Aqueducts, in New York, have shown a reduction in carrying capacity of from 8 to 12%, caused by black slimy accretions on the interiors of these structures. These growths begin to appear almost as soon as the aqueducts are put in commission, and their maximum effect is felt after a comparatively short period of operation. It has been found advisable to use mechanical cleaning devices and other methods to keep some of these conduits in effective condition when the maximum delivery has been required.

The diminution of flow thus caused is remarkable when considered in connection with the apparently insignificant cause. The slime when dry appears to be almost impalpable, and certainly does not appreciably reduce the measured cross-section of the current. Its retarding effect, wholly out of proportion to its bulk, is due to the extremely fine filaments, of the organisms of which it consists, intimately mixing with the water in proximity to the perimeter of the conduit. J. R. Freeman, M. Am. Soc. C. E., in his report on New York water supply of 1900, has aptly compared this effect to that produced on a larger scale in rivers by a growth of eel-grass. This slime is fundamentally organic in character, although doubtless it picks up a considerable proportion of inorganic matter from the water. The writer does not recall the genus of the algæ constituting it, although it differs essentially from the algæ or moss referred to by Mr. Sheley as found in some open channels in California. The biological departments of the water supply systems of New York and Boston, however, have a complete classification of these organisms.

In the writer's investigations as to the condition and hydraulic efficiency of water supply mains in various cities, he has found that many, particularly cement-lined ones, carry a heavy growth of algæ, in fact, so heavy that it is sometimes necessary to relay such mains.

Thus it appears that a closed conduit may be expected to have little or no advantage over an open one, and the disadvantages in cleaning a closed conduit, if it should become necessary, are manifestly greater than in an open section.

As a matter of fact, the writer has not noticed any serious effect from algæ growth in masonry irrigation conduits in the Northwest. This may be largely due to the silt frequently carried by these waters, particularly during times of maximum use. It is believed, however, that the character of the water has a great influence on algæ growths, which vary materially in different localities on that account. Waters high in nitrates usually induce heavy growth.

In irrigation canals, operating conditions frequently tend to nullify some of the disadvantages pertaining to these accretions. The maximum use of water for irrigation is confined generally to a comparatively short period, and the effect of organic growth, therefore, is not brought to bear. During the non-irrigating season, the conduits clean them-

selves, as the organisms perish through lack of moisture, and the accumulations dry up and become detached. When the irrigation season opens, the canals are operated at only partial capacity, and, as the flow approaches the maximum, continual additions of clean perimeter are exposed to the flowing water. As soon as the period of maximum use is passed there is always an excess of carrying capacity, amply sufficient to compensate for any diminution in hydraulic effectiveness which may have been caused by organic growth. Mr. Hopson.

Mr. Dunham brings up the question of a closed *versus* an open conduit. This was quite carefully considered, and the following are the main reasons that governed the writer in advocating the type built:

A closed conduit on steep mountain slopes, as in the Tieton Cañon, would necessarily imply a covering, not only of concrete, but of earth and rock, which would accumulate in process of time even if not placed at first. Such covering would involve unequal loading, of uncertain and possibly very severe character, and would necessitate a considerably heavier cross-section of masonry and more plentiful reinforcement. The conduit cross-section adopted is practically as heavy as could be handled advantageously by the process described, and it appeared that a closed section would probably require to be built in place, under the disadvantageous conditions referred to in the paper as inherent to that method of construction.

It may also be mentioned *en passant* that, at the time this design was under consideration, the difficulties in jointing a closed conduit appeared to be much greater than in an open one, and although events subsequently showed that joints could be made very satisfactorily in the closed tunnel section, it appeared unduly hazardous at the time to adopt that type for the much greater length of the open conduit.

The advantages of working in the full light of day, the greater convenience of access and observation, as well as inspection, were also factors of no mean importance in making the selection.

It should be borne in mind that on a location like this the conduit is constantly exposed to falls of masses of rock from the bluffs. At one point near the conduit, but on the other side of the river, the writer observed such an occurrence, when masses of rock aggregating possibly a thousand tons crashed down the hillside. Many of the detached masses, weighing hundreds of tons, plowed their way through the rocky talus as through butter. No conduit, covered or uncovered, would remain whole under such impact. In the Tieton Canal provision has been made for these contingencies, for they will inevitably occur, and assuredly will break the structure, no matter what precautions are adopted.

One break actually occurred a few months ago, when a 30-ton rock cut away two sections like a knife ripping through paper. Waste-

Mr. Hopson. gates at intervals along the conduit provide for the sudden emptying of the conduit whenever any emergency arises, the controlling devices being arranged so that any sudden rise or fall of the water level will instantly break an electric circuit, open the gates, and, by emptying the conduit, minimize the danger.

An avalanche of rock breaking a closed conduit might merely cut it through and release the flowing water down the mountain side; there is an equal chance that it might crush it and instantly block a stream of 300 sec-ft. flowing at a velocity of more than 9 ft. per sec. The effect of water ram by such stoppage would be disastrous in the extreme. It might, and in all probability would, irreparably rupture and destroy a great length of the conduit, unless its solidity and strength were greatly in excess of that of the present structure.

The maximum capacity of a closed circular conduit is attained at about 95% of the full depth, not when it is running full. In irrigation operation there is frequently a tendency to operate at maximum capacity, and often above safe capacity. Even in the carefully operated aqueducts of the Boston Water-Works system, the writer has known of cases where structures, designed to be operated at water gradient, have been placed under a head, and their operating margin of safety cut down almost to the vanishing point, in order to force a maximum quantity through them in times of scarcity.

There is a great difference between the quality of the operation of the great Eastern water supply systems and a rough-and-ready Western irrigation plant, even when under Government auspices. One may confidently expect that a closed conduit on an irrigation project will be operated ultimately under a head, no matter how conservative the intention of the designer may have been. A closed conduit thus operated undergoes a much severer strain than would appear at first glance. At certain stages there is a conflict between the tendency of the water to flow at the level of maximum capacity and at full depth under pressure, resulting in partial vacuum, air compression, and shock. All these disadvantages are avoided by the open section, which precludes any attempt to crowd the conduit beyond what it should carry.

It will thus be seen that the principal reasons against the closed conduit are of an economic nature. With a much greater expenditure, the conduit could have been closed and rendered safe against many, if not all, of the incidents referred to; but, it should be recalled that engineers engaged on irrigation work never have at their disposal the sums that are expended for the solidly built Eastern aqueducts. The Tieton Canal, of about 200 000 000 gal. capacity, cost about $10 per ft., on a location of the most difficult character, and with labor and material costs at a very high figure. The Wachusett Aqueduct of 300 000 000 gal. capacity, cost about four times as much, with a location and all building conditions of the most favorable character.

Mr. Dunham mentions the "bad hydraulic behavior" of the canal, but the writer does not quite understand the reference. The paper shows that the canal has what the writer considers good hydraulic behavior, not bad. A canal which actually carries with safety somewhat more than the quantity for which it was designed fully serves its purpose. The vagaries of flow referred to in the paper are principally matters of academic interest, and are not of import. As concrete conduits of this length and capacity have seldom, if ever, been built on such slopes and with such velocities of flowing water, it was thought that it would be of interest to the members of the Society to give direct reference to the actual details of operation. Mr. Hopson.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1182

TWO REINFORCED CONCRETE COAL POCKETS.

By Myron S. Falk, M. Am. Soc. C. E.

The type of coal-pocket construction used in New York City by retail coal dealers has, until lately, consisted of a timber structure supported on brick walls, or on wooden posts.

These pockets have wooden bottoms and sides, and are arranged so that coal teams and carts can be driven below and filled promptly by opening a chute in the bottom of the bin.

On account of the fire risks connected with such structures, and perhaps even more on account of the rapid deterioration of the timber and the difficulty of making repairs, a number of reinforced concrete pockets have lately been constructed. This paper describes two pockets of this kind built during the past year.

Pocket No. 1 is constructed entirely of reinforced concrete. It is on Chauncey Street, near Evergreen Avenue, Brooklyn, on a siding of the Long Island Railroad, and was built for the Peoples' Hygienic Ice Manufacturing Company, by the Haiss Manufacturing Company, of New York, from plans prepared by Mr. Ernest Abs-Hagen, the engineer of the company. Albert B. Hager, Assoc. M. Am. Soc. C. E., and the writer acted as consulting engineers for the owners.

In Pocket No. 2, only the posts and bottom of the bin are of concrete; the sides and roof are of timber. It is on the east side of the Harlem River, near 177th Street, New York City, and was built for Olin J. Stephens, Incorporated, by the Godwin Construction Company, from plans prepared by Messrs. Monks and Johnson, Engineers.

PLATE XXVII.
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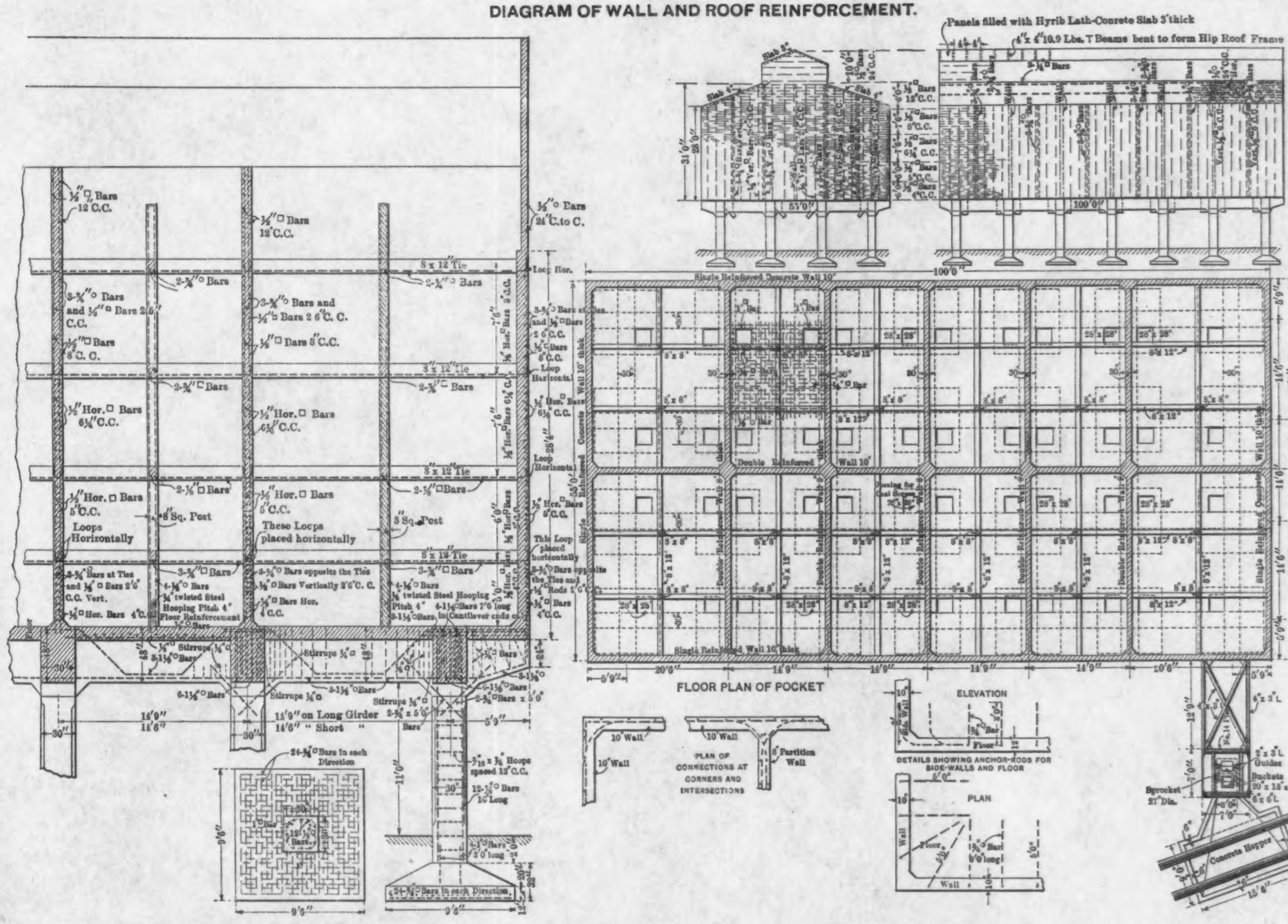
REINFORCED CONCRETE COAL POCKETS.

DIAGRAM OF WALL AND ROOF REINFORCEMENT.



Pocket No. 1 has a capacity of 4 000 tons. Its dimensions are 100 by 55 ft., over all, and its height from the ground to the high point on the roof is 60 ft. 6 in. It is carried on twenty-eight reinforced concrete posts, each 30 in. square, spaced 12 ft. 5 in. apart in the clear, and differs greatly in its manner of support from Pocket No. 2, in which the columns are spaced in longitudinal rows. The pocket overhangs the outside row of columns by 4 ft. 6 in., the floor-beams are cantilevered beyond the columns, and the weight of the reinforced concrete side-walls does not rest directly on a beam over the columns, but is supported on the cantilevered floor-slab. A similar form of construction was adopted for Pocket No. 2.

Pocket No. 1 is divided into twelve compartments by interior reinforced concrete partitions, uniformly 8 in. thick, which are tied to each other and to the outside walls by reinforced concrete ties, 8 by 12 in. in section. These ties are supported at their third points by 8 by 8-in. posts. The outside walls, heavily reinforced, as shown on Plate XXVII, are 10 in. thick.

The weight of the coal is carried on a concrete slab 16 in. thick, reinforced in two directions by $\frac{7}{8}$-in. corrugated bars 6 in. from center to center. The slab, in turn, is supported by the floor-beams, which are 48 in. deep and 30 in. wide. These are reinforced by $1\frac{1}{8}$-in. bars, six at the bottom and four at the top, bent as shown on Plate XXVII, which also shows the stirrups and the general reinforcement in the cantilever beams and the walls. The 30-in. columns are reinforced with twelve $\frac{7}{8}$-in. and four 1-in. rods, hooped and tied as shown. The reinforced footings of the columns rest on hardpan, and are 9 ft. 6 in. square.

Coal is delivered by bottom-dump cars into a concrete hopper on the siding, from which it is transferred by a bucket conveyor to the center loft of the pocket. It is carried from that point by a single-strand flight conveyor running the length of the pocket to the various compartments, trip-ups being provided so that any desired bin may be filled. Each bin has four bottom chutes, each 24 in. square, through which the coal is delivered into the wagons. Screens are placed in the chutes in order to give the coal a final screening before delivery.

The walls of the pocket were designed so that any compartment might be filled while neighboring compartments were empty.

The difficulties of constructing this pocket were many, because the

reinforcing rods in the outside walls acted as an impenetrable fence and prevented the placing of concrete within the bin; consequently, all concrete had to be carried to the full height of the outside walls, and then lowered inside the pocket. The method adopted by the contractors appeared to overcome this difficulty very satisfactorily. A traveling concrete mixer, with a bucket conveyor extending the full height of the outside walls, was erected on the outside of each of the longer sides of the pocket, and, from the top of the conveyor, wooden troughs conducted the concrete directly to its proper place. The scheme appeared to be feasible and not expensive, because, the contractor's main business being the building of coal machinery and hoists, he could construct the two conveyors out of stock on hand, and presumably knew that they would operate satisfactorily. Unfortunately, the conveying apparatus broke down very frequently, and, unless repairs were made within a few minutes, the concrete in the bucket conveyor began to set, thus causing serious delay while men chopped the buckets and operating mechanism clear.

When the apparatus was in working order, however, no better scheme could have been desired. It was possible to place the concrete in any portion of the floor, the walls, the posts, or the ties, without any further handling. As there was a clause in the specifications which permitted the use of wet concrete, the trough system of chuting the concrete was an admirable plan.

Pocket No. 2 has a capacity of 1 600 tons. Its dimensions are about 62 by 46 ft., over all, and its height to the top of the ridge is 60 ft. 10 in. It is constructed in such a manner as to allow for further additions longitudinally.

On account of the difficulty encountered in placing concrete in Pocket No. 1, it was decided to make No. 2 of concrete only as far as the foundations and floor. As shown by Plate XXX, this portion contains really mass concrete, which was easily put in place.

The remainder of Pocket No. 2 is of timber, and all the timber used as falsework for the concrete construction was afterward embodied in the pocket itself, so that the cost of material for forms was very small.

The pocket rests on four lines of columns, nine in a row, the rows being 16 ft. 8 in. from center to center, so as to allow plenty of room for large coal wagons. The ends of the pocket overhang 5 ft. from the

PLATE XXVIII.
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FIG. 1.—REINFORCEMENT FOR COAL POCKET No. 1.

FIG. 2.—REINFORCEMENT FOR COAL POCKET No. 1.

centers of the last line of columns. The columns are 15 by 20 in. in cross-section except the center one in each row, which is 18 by 20 in., the former being reinforced with four $\frac{7}{8}$-in. round rods, with $\frac{3}{8}$-in. hoops, and the latter with four 1-in. rods, with $\frac{3}{8}$-in. hoops. The columns rest on concrete footings carried n piles.

The concrete beams spanning the columns are 15 or 18 in. wide and 34 in. deep. They are reinforced in different ways, on account of their location, but in general have eight 1-in. rods at the bottom at the centers of the beams.

The floor-slab is $6\frac{1}{2}$ in. deep, and is reinforced every 6 in. in a direction at right angles to the main beams, by two $\frac{1}{2}$-in. rods, spaced 1 in. from the top and bottom of the slab.

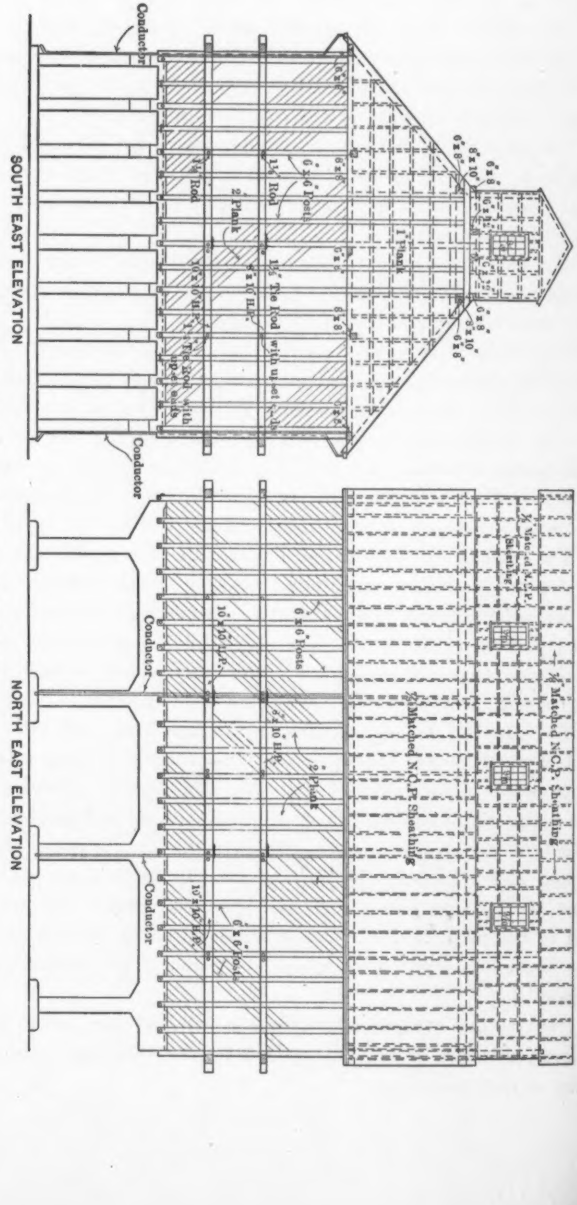
The timber portion of the pocket is of the usual type of construction, with timber tie-rods through the bins, and timber rods all around the exterior of the vertical studding, as shown by Figs. 1 and 2.

Coal is unloaded from barges at the end of the pier by a clam-shell bucket mounted on a revolving Browning locomotive crane, and is deposited in a hopper from which it is carried to the top of the pocket on a conveyor, supported on a timber trestle.

The method of placing the concrete in this pocket was adopted because the locomotive crane and clam-shell bucket had been delivered to the owners before concreting was commenced, and the contractor was permitted to use them. The clam-shell bucket unloaded the sand and gravel from the deck barges into carts which in turn unloaded the material near the batch mixer close to the pocket.

The concrete mixer had elevated storage bins, and after a boat load of material had been unloaded, the locomotive crane was moved down to the mixer and, with the clam-shell bucket, hoisted the sand and gravel into the bins. Then, when concreting was in progress, the output of the mixer was deposited directly in the same clam-shell bucket, now free from the duty of placing the raw materials. The boom of the crane was of sufficient length to deposit concrete in any part of the pocket. The concrete was dumped by the engine runner, who controlled every motion of the bucket. The scheme was most successful.

The vertical studding forming the sides of the pocket rests on T-irons embedded in the concrete beams; the studding is also held by bolts, as shown by Fig. 3.



COAL POCKET FOR OLIN J. STEPHENS, INC.
NEW YORK CITY
FIG. 1.

FIG. 1.—CORNER OF COAL POCKET NO. 1.

FIG. 2.—COAL POCKET NO. 1, COMPLETED.

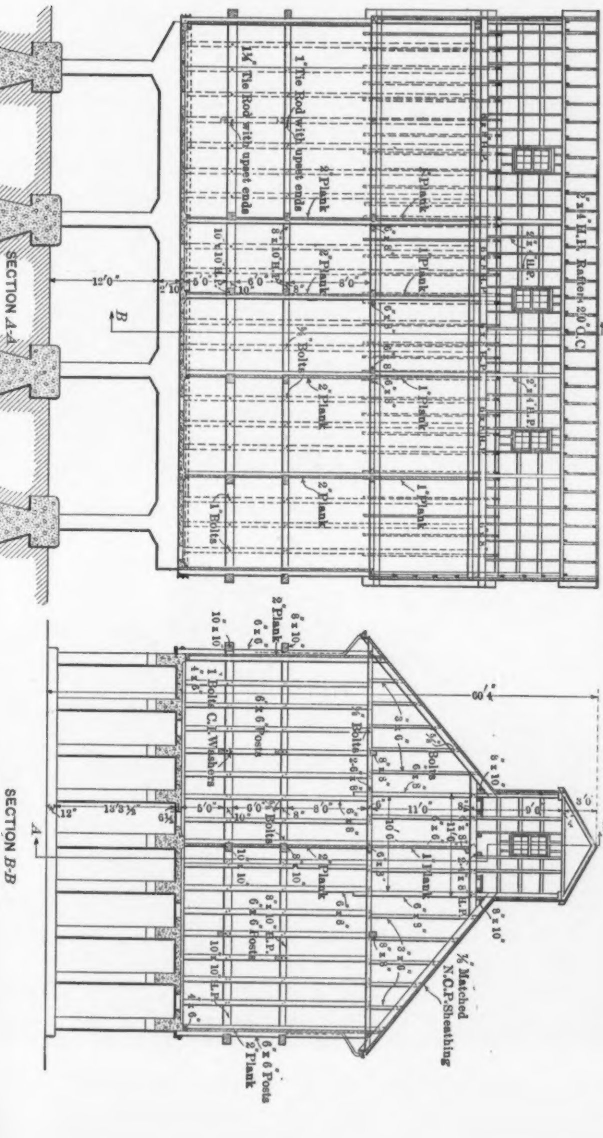


FIG. 2.

SECTION B-B

COAL POCKET
FOR OLIN J. STEPHENS, INC., NEW YORK CITY.

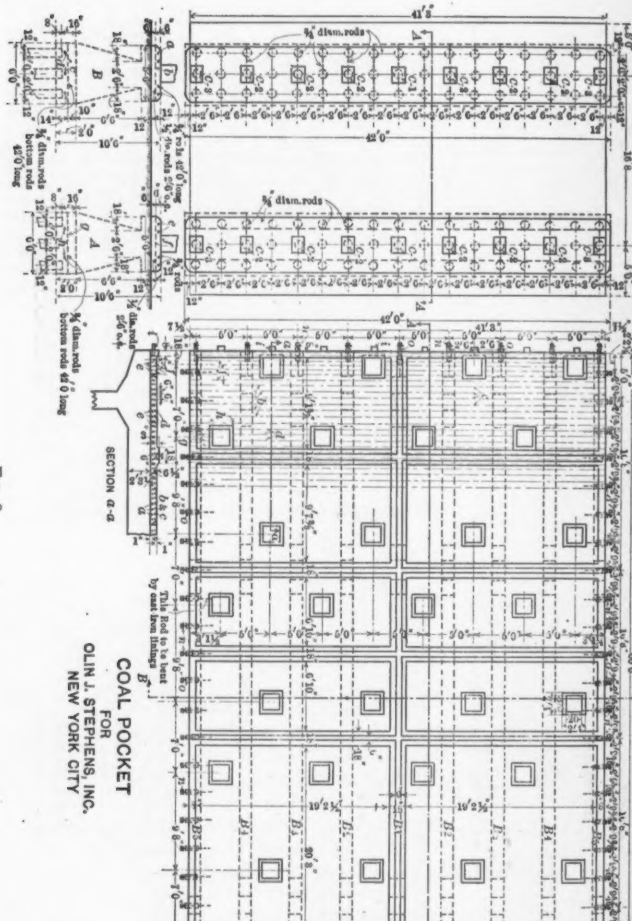

COAL POCKET
FOR
OLIN J. STEPHENS, INC.
NEW YORK CITY
SECTION a-a
This Rod to be bent by cast iron fittings
¾" diam. rods

FIG. 8.

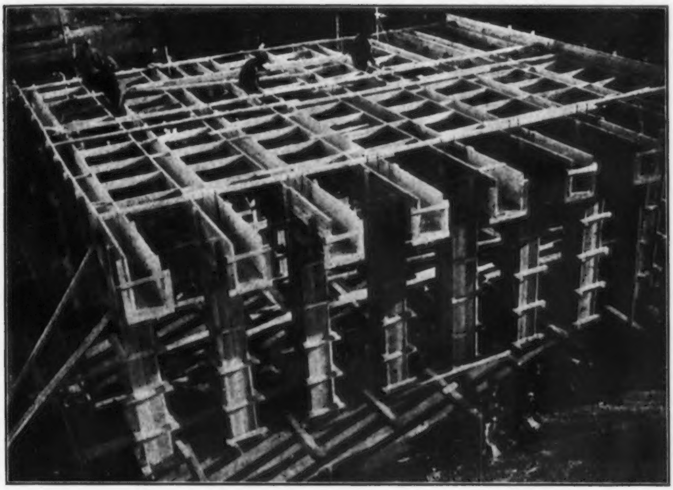


FIG. 1.—FORMS FOR CONCRETING, COAL POCKET NO. 2.

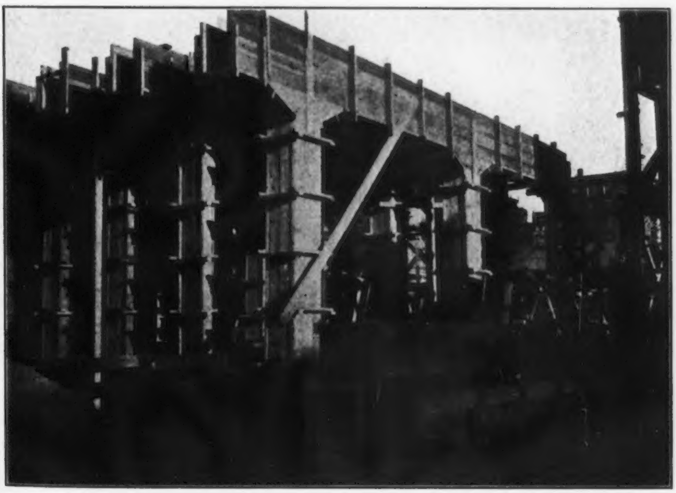


FIG. 2.—FORMS FOR CONCRETING, COAL POCKET NO. 2.

PLATE XXXI.
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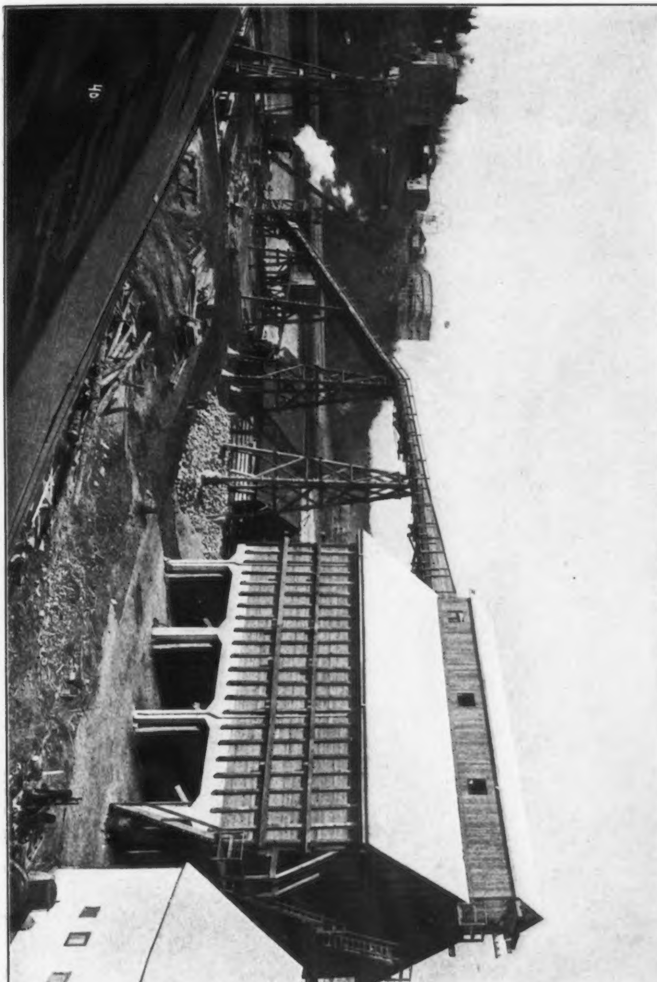

COAL POCKET No. 2 AND CONVEYOR.

The actual cost figures of these two pockets are not of general value, as the local conditions at the sites of the buildings were so totally different. It is sufficient to say that, compared with Pocket No. 1, it is the writer's opinion that Pocket No. 2 furnishes a type of structure which is more easily erected, uses cheaper material throughout, and provides a building which, viewed from all standpoints of an owner, is entirely satisfactory.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

TRANSACTIONS

Paper No. 1183

RUST—AS SHOWN IN THE REMOVAL OF A SEVENTEEN-STORY BUILDING*

By T. Kennard Thomson, M. Am. Soc. C. E.

With Discussion by Messrs. E. L. Verveer, A. W. Carpenter, F. Lavis, S. M. Purdy, R. A. MacGregor, J. B. French, F. W. Gardiner, and T. Kennard Thomson.

The Gillender Building, a seventeen-story structure at the northwest corner of Wall and Nassau Streets, New York City, was built in 1896, and removed in 1910.

When built, all the columns were encased in solid brickwork. The steelwork received one coat of paint in the shop and two after erection, but on removal, showed little evidence of ever having been painted at all.

From the top to the bottom, wherever the spaces between the brick and steel were filled with Portland cement mortar, there was no rusting, but, wherever the mortar did not fill such spaces completely, rusting had begun. Generally, the under sides of the top and bottom flanges of the floor-beams had begun to show rust, while the web and upper surfaces, having been in contact with mortar, were in good condition.

The worst rusting of all was from the sixth floor down, on the northeast corner, where the columns had been against the adjoining building, on the north side. The cover-plates of these columns looked

* Presented at the meeting of October 19th, 1910.

as if they had never been painted, but had stood in the open, exposed to all weather, for 6 or 7 years. On these columns, one-half, in volume, of many rivet heads could easily be removed.

This building had been erected by first-class contractors and with first-class materials; and although the rusting had not yet made the building unsafe, there is no telling how soon it would have become so.

It would seem that if the columns had been encased and filled with wet concrete there would have been little danger of rust, and they could thus have been easily protected from electrolysis. Oil or oil paints should not be placed on steel to be thus encased.

Messrs. Trowbridge and Livingston are the architects for the thirty-nine-story Bankers' Trust Building which will take the place of the Gillender Building, and Messrs. Marc Eidlitz and Son are the contractors, to whom the writer gives his thanks.

DISCUSSION

Mr. Verveer.

E. L. Verveer, Assoc. M. Am. Soc. C. E. (by letter).—This paper calls to mind some causes of the rusting of steel in modern buildings which are deduced from the writer's observations of structures in the course of erection.

Specifications very often require steel columns to be encased with a layer of cement mortar before the surrounding brick, stonework, or other fire-proof material, is put in place. This is done to prevent the steel from oxidizing by coming in contact with moisture, and is an additional precaution, as paint itself is not an absolute preventive.

The owner, being anxious to have the building ready for occupancy as soon as possible, so that he may derive an income from his investment to meet his fixed charges, inserts a time limit in the contract; or, in other words, the contractor is bound by a "time clause," which, if not adhered to, leads to "liquidated damages." Consequently, the work must be speedily done. The cement mortar may be placed around the surfaces of the steel, as required by the specifications, the workman keeping ahead of the mason or bricklayer, as the case may be. Not being thoroughly dry, or perhaps having been struck by objects coming in contact with the column, pieces of the mortar fall off, and, as the work of the other trades proceeds so rapidly, they are not replaced. The steel column, then, at these bare spots, is exposed to the moisture or moist air which, from one cause or another, may creep in, thus creating the condition mentioned in the third paragraph of Mr. Thomson's paper.

It does not seem to the writer that sufficient care is taken in the construction of party walls or walls adjoining adjacent buildings. It may be that, because hidden from view, any construction is thought to be permissible. Whether or not this is the case, the brick is quite often improperly laid, and insufficient mortar is placed in the joints, so that air spaces exist. Then, too, the mortar, after drying, sometimes shrinks away from the brick, or a slight settlement of the building may cause voids at the joints. The bricks also may absorb the moisture, leaving the mortar to crumble away. In any case, these conditions permit the moisture or moist air to reach the steel columns and beams in the wall and to promote oxidation.

Property lines frequently overlap existing buildings, so that it is not possible to make the party wall of the required thickness. Where columns occur in such walls, there is often only 4 in. left between them and the wall of the adjoining property. In such cases only a single brick can be placed against the column face, and there cannot be a good bond. Again, with only a small space in which to work, the bricks are not properly laid, and the steel is practically exposed.

In several cases where an old building abutting a modern steel one has been torn down to give place to a new steel structure, the single layer of bricks forming a face for the wall columns has toppled over when the side walls of the old building were razed, leaving the steel exposed. This was good evidence that the bricks were not well bonded and did not serve to protect properly the paint on the steelwork, in other words, did not help to prevent oxidation. Mr. Verveer.

In the best practice, the underside of the flanges of steel floor-beams is covered with 2 in. of some kind of concrete. The object of this is to prevent the flames, in case of fire, from acting directly on the beam, and also to protect the steel from rusting. Often, however, the flange is simply covered with wire mesh and the plaster applied to this. Plaster is porous and readily absorbs moisture and, consequently, does not of itself protect the flange from rusting, but rather helps the oxidation by being a vehicle. The paint is then the only protection for the steel, and, as paint is not an absolute preventive, the steel flanges will rust in time. This, perhaps, is why the undersides of the flanges of floor-beams frequently show signs of rust.

The writer does not believe that there is any absolute preventive of the oxidation of steel, known at the present time, which can be commercially applied, and, consequently, he deems it a mistake to think that steel encased in brick, cement, paint, etc., will not require inspection from time to time.

A. W. Carpenter, M. Am. Soc. C. E.—While the Gillender Building was being removed, the speaker visited it for the special purpose of observing the condition of the steelwork as regards corrosion. His observations and conclusions were so contrary to those of Mr. Thomson, and have been so well sustained in general by other observers, that he feels that the paper will create a wrong impression as to the condition of this steel. Mr. Carpenter.

At the time of the speaker's visit the frame was stripped down to about the fifth floor. He went up to the sixth floor, and there made a close examination of several of the accessible columns and beams on the west side of the building. At this point the building was exposed to the weather, as there was no adjoining building at this height, but there was no evidence of destructive corrosion anywhere. In some scattered spots the surface was rusted, but no pitting or formation of rust scale was observed. It is very likely that some of these spots rusted before the steel was encased or possibly after it was uncovered. The tops of the floor-beams were rather rusty generally, but it was merely surface rust; there was no pitting or rust scale.

The speaker's observations regarding the paint, the condition of the different surfaces of beams, and of surfaces in contact with mortar and otherwise, were generally in no way in accord with Mr. Thom-

Mr. Carpenter. son's description. Where mortar came in contact with painted surfaces, the oil vehicle of the original paint film was generally removed, leaving only the dry pigment adhering to them. There was plenty of this dry pigment on such surfaces, which were generally distinctly colored by it, and much good paint film, as will be mentioned later, so that the author's statement, that the steelwork "showed little evidence of ever having been painted at all," is certainly technically incorrect. The speaker cannot dispute nor affirm the statement that there was no rusting where the mortar came in contact with the steelwork or with the painted surfaces, as unfortunately he did not keep a record of observations on this point. He can absolutely dispute, by his own evidence and that of other witnesses, the statement that wherever the mortar did not fill the spaces between the brick and steel completely, rusting had begun. His observation, and that of the person who made joint examination with him, was that, where mortar had not come in contact with the steel or paint, the painted or unpainted surfaces were in perfect condition; this condition was especially noted on the under side of the outside top flange of an outside beam along the west wall, where the paint was so perfect that it came off in elastic strips when a knife blade was applied. Under the head of the same beam there were two rivet heads which evidently had never received any paint, and had not been in contact with mortar; these heads looked exactly like those of newly-made rivets, the blue scale on them being perfect, and no touch of rust showing.

The author refers to the upper surfaces of the floor-beams as being generally in good condition; the tops of the floor-beams, of the floor which the speaker examined, were rather generally rusted, but it was merely surface rust, and there was no pitting or rust scale formation. That the tops of floor-beams should be rusted is to be expected, and it is most likely that the rust formed before the beams were encased, as it happens frequently that such surfaces are not painted in the field, and are subjected to much abrasion from the feet of workmen, etc. The speaker wishes it to be understood that the observations recorded in this paragraph were made from one examination of a small portion of one floor of the building, and that he does not generalize from the same; but in view of these observations, he fails to see how Mr. Thomson can generalize to the contrary on so many points.

After his brief examination, the speaker left the Gillender Building, feeling that it was a notable example of the excellent preservation of steel in building construction, and that, when its condition was made generally known, it would cause a feeling of security regarding the permanence of such construction. It was with considerable astonishment, therefore, that he read Mr. Thomson's rather "alarmist" paper; and, thinking that his own observations might not apply

Mr. Carpenter.

to other parts of the building, he made inquiry of others of his acquaintance who had examined other parts of the steel. These observers agree with the speaker regarding the excellent condition of the steel, except in the cases of one or two columns in the northeast corner of the building (which are mentioned by Mr. Thomson), one or more columns in the southeast corner, and some roof-house framing. The information derived from these observers, with regard to these exceptions, is as follows: Some of the northeast corner columns above the roof of the adjoining building on the north, which extended up to about the sixth floor of the Gillender Building, were rather badly rusted on one side only, but not enough to cause any appreciable loss of section as yet. No information could be obtained regarding the exact condition of the columns in the southeast corner. Some roof-house framing had been corroded considerably at points where leakage from the roof and sides fell on this framing. All the observers agreed that they recognized no such severe corrosion of columns, either in the main section or in rivet heads, as Mr. Thomson's description indicates.

The reason for corrosion on a few columns—perhaps less than 2% of the total number—while the others were practically untouched, has not been pointed out very satisfactorily. It is significant that these columns were in the corners of the building, and it is possible that the weather had a greater effect there, and that the corrosion occurred where the weather effect was most concentrated or the brick and mortar work of the poorest quality.

Observers of the steel after its removal have informed the speaker that the column bases and grillages were practically in perfect condition. This was also true of the interiors of the box-columns and the inside web surfaces of the doubled channel members, where the channels were separated by the width of connecting gusset-plates. They have also stated that the paint inside the box-columns and channel surfaces was in perfect condition.

The observations regarding the condition of the paint inside the box-columns should be noted as valuable information, also as in contradiction to Mr. Thomson's statement. The paint on outside surfaces, where the mortar did not come in contact with them, was not invariably found in good condition by the other observers, who state that in some cases they found rust, and the speaker thinks that water probably obtained access to such surfaces.

There appears to have been no evidence of electrolytic corrosion in this building.

Perhaps it is pertinent to note that the New York Board of Fire Underwriters has published a "Report on the Demolition of the Gillender Building,"* in which the following is found:

*Over the signature of Mr. F. J. T. Stewart, Superintendent of the Bureau of Surveys.

Mr. Carpenter. "Inspections of the steel work made at regular intervals during removal indicate that it was in practically as good condition as at the time when the building was originally erected. Some evidence of corrosion with slight pitting was observed on the column in the wall at the northeast corner of the building at the 7th and 8th floors. This point was near the line of the roof of the Stevens Building, and the trouble was apparently due to defective column covering which permitted dampness and other atmospheric conditions to penetrate to the steel work. Some slight evidence of corrosion has also been reported on one of the columns at the southeast corner of the building. An additional examination of the steel was made at the Ames Bolt Works, in Jersey City, while the columns and parts of the structure were being dismembered. All parts were found in good condition, including rivets, with minor exceptions. The cement mortar used in connection with the masonry work covered the steel unusually well, and proved to be an excellent protection against corrosion. The paint used on the steel work of the building, as near as could be ascertained, was two coats of iron oxide mixed with linseed oil. Where cement had come in contact with the paint on the columns and other portions of the steel work, it had destroyed the linseed oil, while on the inside of the column plates where the cement mortar did not touch the steel it still had a glossy appearance.

"Conclusions:

"1st. While some of the steel work showed slight corrosion and pitting, there was nothing to cause any special apprehension regarding the ability of such buildings to endure for an indefinite term of years. However, the presence of corrosion where the steel was exposed to the weather emphasized the importance of thoroughly protecting against moisture.

"2d. A covering of cement mortar protects steel from corrosive influences better than any form of paint at present in use (the steel work in some buildings recently erected has been coated with cement mortar).

"3d. It is important to paint the steel both at the mill and after being erected at the building, before the cement coating is applied."

The paint observed by the speaker had the characteristics of graphite and linseed oil, instead of iron oxide. The destructive action of cement on linseed-oil films, and on paints made with linseed oil as a vehicle, was discovered by the Engineering Department of the New York Central and Hudson River Railroad Company, in making experiments to determine the proper preservative coating for the steel in the new Grand Central Terminal. It may not have been a new discovery, but apparently it was not known to any of the paint manufacturers prior to that time, although it has been generally recognized since. These experiments, as well as observations of steel which had been painted and encased in cement mortar and concrete, showed that coatings of paint with linseed oil as a vehicle and any of the ordinary pigments, red and white lead, graphite, iron oxide, carbon, etc., were deprived of the oil soon after coming in contact with the

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mortar or concrete, nothing being left but the dry pigment. The experiments were made on small coated-steel plates embedded in blocks of mortar and concrete, the blocks being kept in a dry room after moulding. It was also found that certain coal-tar and asphalt coatings were not affected by the mortar and concrete, so that, since that time, such coatings have been used between steel and mortar or concrete in steel-building construction.

The necessity for paint coatings on metal encased in concrete is questioned by many. It depends on several factors: In certain cases the steel should be painted, and in others it is not necessary. If there is sufficient concrete of proper density around the steel, painting is not necessary. This would be the case with small rods entirely surrounded by a relatively thick coating of mortar, for, even if the concrete is somewhat porous, it is generally strong enough to resist the expansive force of oxidation. If this same quantity of steel were rolled out into a continuous sheet, and concrete or mortar of the same thickness were placed around it, the concrete would have very much less strength to resist the expansive force of rust, and a paint coating which would not be acted on by the concrete might be of very great assistance in preventing corrosion.

The case of a series of small rods with 1 in. or more of concrete on all sides is quite different from that of a sheet of metal, or of a column, say, 18 in. square, with concrete 2 in. thick surrounding it. In the first case the concrete shrinks tight on the rods, and its clamping strength is so great that it would take a very great force per unit of metal surface to force it off. In the second case, the concrete, in setting and hardening, may shrink away from the surface, and, as its clamping strength is comparatively small, a slight force from the surface of the metal would force the concrete away and make room for further corrosion.

It is probable that all mortar and concrete will leave voids next to the metal, and then, if corrosive gases or liquids are applied to the outside of the casing and the latter is permeable (as it is generally, in some degree), rust will eventually form in the voids next to the metal. If the concrete covering is not strong enough, this rust will force it away, exposing more surface for corrosion, and finally, the entire concrete coating will be forced off by the expansion of the rusting metal. Where large surfaces are faced with concrete, as is usual with encased columns and girders, it would seem that a paint coating which will prevent rust action from starting in the voids, and will be a good protection itself, irrespective of the concrete, is a desirable thing, and is a necessary precaution where the faced parts are exposed to the weather, to steam, gases, etc.

The bond of concrete to flat surfaces will be found to be much greater if such surfaces are painted with proper coatings than if they

Mr. Carpenter.

are unpainted. The practice, now somewhat common, of omitting even a shop coat of paint, on girders and columns which are to be faced with concrete, and putting in this material, even with rust often well developed on the surfaces generally, is a very doubtful one, to say the least.

In the Gillender Building the 4-in. brick and mortar facing was generally thick enough to keep the corrosive elements away from the metal, even though the paint coating was of very little service. The exceptions—the columns in the northeast and southeast corners—might have followed the general rule if the proper kind of paint had been applied. The New York Building Law now requires a minimum thickness of 8 in. for brickwork encasing exposed columns, which, if combined with proper workmanship, would seem to insure permanence in this portion of the steelwork, beyond any doubt.

The evidence of the Gillender Building seems to point especially to the freedom from corrosion of interior steelwork and to the principal necessity for protecting the steel along exterior walls.

Acknowledgments for information regarding the condition of portions of the Gillender Building, not observed by the speaker, are due to Mr. A. J. Post, of the firm of Post and McCord, the contractors for the steel and erection of the original building, as well as for the new building, and to Mr. J. L. Holst, Engineer of Structures, Electric Zone, New York Central and Hudson River Railroad.

Mr. Lavis.

F. Lavis, M. Am. Soc. C. E.—The speaker has nothing to add to this discussion from his experience, but wishes to call attention to an article by DeWitt C. Webb, M. Am. Soc. C. E., in *Engineering News*,* which seems to show a materially different result from that recorded by Mr. Thomson, although the fact that the mortar, in the case referred to by Mr. Webb, was mixed with sea water and made of Rosendale cement, may have caused the corrosion. The article is as follows:

"The Steam Engineering Machine Shop at the U. S. Naval Station, Key West, Fla., is a one-story, steel-framed, brick building about 60 x 140 ft. in plan, completed in the summer of 1899. The steel columns of this building are composed of two 12-in., 25-lb. channels, 10-in. apart and latticed. At the corners of the shop these columns are completely enclosed by and filled with the brick work. The intermediate columns are not enclosed on the inside nor filled.

"The brick were laid with mortar composed of one part Rosendale cement and two parts sand, mixed together with sea water. Walls were laid close around all steelwork and spaces between brick and steel were well filled with mortar.

"In March, 1901, vertical cracks were noticed in the pilasters at the corners of the shop. These cracks first appeared in the centers of

* September 1st, 1910, p. 230.

the pilasters at about mid-height and gradually extended up and down. In April, 1902, one of the corner pilasters was opened and the steel column, where in contact with the mortar, was found to be badly rusted. The same condition was found to exist at all the corners and they were torn out and rebuilt, the brickwork in rebuilding being kept ½ in. from the steel. No further trouble has been experienced with the corners but cracks have appeared in many of the intermediate pilasters and six of these have been rebuilt. A recent examination of a portion of one of the columns enclosed by the original brickwork showed the steel considerably rusted at all points where the mortar was in contact while adjoining areas not touched by mortar were entirely free from rust." Mr. Lavis.

S. M. Purdy, M. Am. Soc. C. E.—During the construction of the Market Street Subway, in Philadelphia, large quantities of reinforced concrete were used. At times the reinforcing bars were more or less coated with rust. On one occasion some 1¼-in. bars, having an incrustation of rust almost $\frac{1}{16}$ in. thick, were placed within the forms for a wall and the concrete poured in the usual manner. In less than 2 weeks, owing to a change in plans, it became necessary to remove this wall, and the speaker, knowing the condition of the steel previous to concreting, took especial note of its appearance after removal. The rods were found to be of a natural steel-gray color, entirely free from any indication of oxidation. It was at once apparent that the oxide had entered into chemical combination with the cement, and this view was further strengthened by the fact that the concrete adjacent to the rods was not discolored. Mr. Purdy.

There is evidence on all sides that Portland cement is an almost perfect protection for steel. Beams and grillages are constantly being removed from walls and foundations where they have been encased in concrete, and, in every instance where the concrete is sound and the covering complete, the steel is found to be in good condition. With this knowledge in view, it would seem that permanent construction can easily be obtained by the correct combination of steel and concrete, provided the workmanship is thorough. The razing of the Gillender Building shows that, unless the steel is protected by a suitable covering of concrete or mortar, oxidation may be expected, as little reliance can be placed on paint in places where inspection is impossible.

R. A. MacGregor, M. Am. Soc. C. E.—There is a new process which is said to have been successful in the preservation of stone by the application of paraffin. It is also claimed that by the use of this process steel may be protected from moisture and electrolysis. Mr. MacGregor.

J. B. French, M. Am. Soc. C. E.—The speaker recalls some experience which strongly fortifies the author's contention in favor of good concrete or cement mortar as a protection for steelwork against rust. Mr. French.

Mr. French.

In the construction of the short viaduct built in 1898 to connect the Brooklyn Elevated Railroad and the Long Island Railroad near the intersection of Flatbush and Atlantic Avenues, Brooklyn, it was found necessary to connect the bases of the viaduct columns, under the street surface, by a large number of 20- and 24-in. I-beams, most of which were about 29 ft. long. Owing to the peculiar type of construction necessary, these beams were not embedded in a large mass of concrete, but were, for the most part, only covered sufficiently to protect them against rusting, the minimum thickness of the concrete covering being about 2 in.

A 1:2:4 mixture of Portland cement concrete, with ¾-in. stone as aggregate, was used. It was put in very wet, care being taken to have tight forms and to secure thorough contact between the steel and the concrete.

The speaker saw these beams put in and the concrete deposited around them in 1898, and some 6 years later he saw the work torn out, in order to carry out other grade changes; and the showing in favor of good concrete, properly applied, as a protection for steelwork against rust, was certainly very striking. In order to detach the concrete from the beams it was necessary to drill holes in it and put in blasting powder; and the beams, when uncovered, were found to be as clean as when they were rolled, the shop marks being clearly legible. The only rusting was at points where the concrete forms had leaked or where voids had occurred from other causes, permitting air and moisture to reach the steel, but such points were very few indeed.

Soon after these beams were uncovered, the railroad company undertook the elimination of a large number of grade crossings where the streets were to be carried over the railroad tracks and where the lower surfaces of the bridge structures would come within 6 in. of the tops of the smoke-stacks of steam locomotives. On account of the sulphur fumes, the moisture and heat in the mixture of steam and smoke, and the abrasive effect of the hot cinders blown out by the exhaust, it is most difficult to protect steelwork in such a position from corrosion, and most of the expedients tried have been failures.

Largely as a result of the showing made by the use of concrete as described, a design was worked out for these overhead bridges, where all the surfaces exposed to locomotive gases and blast, were covered with a dense coating of concrete or mortar, nowhere less than 2 in. thick, bonded to the body of the floor concrete above by wire mesh wrapped about the steel flanges, this mesh or fabric itself being carefully prevented from coming within 1½ in. of the exterior surface of the concrete. This concrete or mortar protection, it should be understood, was poured as a part of the main concrete floor construction, and not plastered on, as has sometimes been done.

The first bridges built in this manner have now been standing

Mr. French.

about five years, and the under surfaces have been exposed to locomotive gases for that length of time, but apparently no depreciation has taken place, and the railroad company has adopted this type of construction for practically all new bridges similarly exposed.

To make concrete or cement mortar effective to protect steelwork against rusting, it must, of course, be thick enough and dense enough to exclude moisture and air. Neither water alone, as in the case of construction continually below water, nor dry air, will cause rust, but the combination of the two always does. One of the difficulties, therefore, in the use of concrete for the protection of structures exposed to the weather, like railroad bridges, is to place and bond it to the steelwork so that it will not crack and thereby let in the air and water together. The concrete must have sufficient body and must be effectively bonded to the steel by rods, wire fabric, or other means, but when used properly, there is no question about its efficacy.

Mr. Gardiner.

F. W. GARDINER, M. AM. SOC. C. E.—The speaker has observed two cases of the corrosion of iron or steel embedded in concrete. The first relates to iron anchor-bolts in elevated railroad foundations, and the second to metal lath plastered on both sides with cement mortar, mixed in proportions of about 1 part cement to 3 parts sand, and used for outside walls.

Referring to the first case, about 68 elevated railroad column foundations, in Division and Allen Streets, New York City, were cut out and rebuilt on account of the remodeling of the structure in order to provide sufficient clearance for the approach span of the Manhattan Bridge to cross Division Street. These foundations were of brick in cement mortar. The anchor-bolts were of iron, and extended through the whole depth of the brick foundation into a bed of concrete about 6 in. thick, below the brickwork. The foundations were all in sand and gravel above high water, and had been in service about 30 years. The bolts were found to be in a perfect state of preservation, and some wires which apparently had been used to fasten paper labels to them, were found to be intact.

In relation to the corrosion of metal lath used in outside walls and plastered on both sides with cement mortar, it has been found, in three cases where it became necessary to cut out parts of such walls in order to provide for additions, that the metal lath had been badly rusted. Most of the rust was at points where steel studding occurred, and, evidently, was due to the fact that the cement mortar had not filled all the voids around the studding and lath, thus providing air spaces into which moisture from the outside could penetrate. From these observations the speaker does not consider this type of construction to be permanent.

Mr. Thomson.

T. KENNARD THOMSON, M. AM. SOC. C. E. (by letter).—When this paper was written the subject was thought to be of such importance

Mr. Thomson.

that it should be made known as widely as possible; and, in order that no one would have an excuse for not reading all of it, the paper was made very short.

Since that time the girders and grillage beams bedded in concrete have been uncovered and found to be in perfect condition. The box-girders below the water line had been coated with an oil paint, then covered with tar, and afterward bedded in concrete which surrounded and covered them. The steel beams under these box-girders had been well covered with an oil paint and buried in concrete. They had no coating of tar.

The beams and girders were on top of the concrete caissons, which were sunk through the so-called New York quicksand. Near these caissons were a number of 15-in. underpinning steel cylinders which had been jacked down under the adjoining buildings and filled with concrete to within about 2 ft. of the bottom. These steel cylinders had no protective coating of any kind, and were in first-class condition after being in the ground 14 years. From this it might be inferred that the paint and tar on the nearby beams and girders did not do any good, but simply prevented the concrete from adhering to the steel, as in the case cited by Mr. French, where dynamite was required to break the bond. It might also be inferred that New York quicksand prevents the access of air to the embedded steel when there is no flow of water. If the water flows, or is polluted, the result is apt to be different, for bolts taken out of the mud in the North River have been found to be in perfect condition where bedded in wood, while those portions which projected beyond the wood were badly corroded. Mr. Verveer's remarks are to the point, and the inspection he suggests would be very desirable were it at all feasible.

It was thought that the paper had been made short and clear, and the writer was very much surprised at Mr. Carpenter's discussion. Those who read that discussion are respectfully requested to re-read the paper.

The paper stated plainly that, although the rusting had not yet made the building unsafe, it was impossible to tell how soon it would have become so, for the steel had started to rust in many places, and the deterioration might have been accelerated at any time by the access of air or moisture, or by electrolysis, as the paint seems to have been useless.

In this building no evidence of electrolysis was found, but, in New York City, very little precaution has been taken to avoid that danger. Any one who doubts that there is any real danger to be guarded against, due to the electricity in the ground getting into the building, or the electric current in the building escaping into the ground through leaks, broken water pipes, etc., is advised to read a description of the experiments of Mr. U. James Nicholas of Seattle, made by the Govern-

Mr. Thomson.

ment of Victoria, Australia.* In the Bankers' Trust Building, every effort is being made to prevent such a flow of electric current.

The writer regrets that Mr. Carpenter did not observe more carefully and study what he observed, before reaching conclusions so contrary to those of the paper. For instance, the paper states that there was little evidence of paint, and this he characterizes as "technically incorrect," although stating elsewhere that "the paint coating was of very little service." He also quotes the Report of the New York Board of Fire Underwriters, as follows: "The paint used on the steelwork of the building, as near as could be ascertained, was two coats of iron oxide mixed with linseed oil," but asserts that the paint had "the characteristics of graphite and linseed oil, instead of iron oxide," and further, that "there was much good paint film." Notwithstanding all this, no one can tell what kind of paint was used.

When the workmen commenced to remove the steel in the Gillender Building it is stated that some of them had a discussion as to whether or not it had ever been painted; and the writer believes that an inquiry to that effect was made, but the builders truthfully asserted that the steelwork had received one coat in the shop and two after erection. The writer, therefore, stated that there was little evidence of paint, but he did not mean that there was no evidence of the original three coats, which would have been absurd.

Charles H. Nichols, M. Am. Soc. C. E., Chief Engineer for the Architects, Messrs Trowbridge and Livingston, describes and shows photographs of the worst column, which was protected on one side by paint alone because it was too close to the adjoining building to get any protection from mortar.† Mr. Nichols gives it as his opinion, with which the writer agrees, that "the paint contributed very little to the preservation of the steel."

Mr. Carpenter states that the paint was of "very little service" in the Gillender Building, and that a good paint is to be desired in addition to the concrete. This is indisputable, if such a paint can be found.

All seem to agree that the paint in many places had lost its usefulness, but Mr. Carpenter claims that the paint and steel were in better condition where not touched by mortar; and yet the worst column, as has been shown, had no mortar whatever on the corroded side. Therefore, the writer sees no reason for qualifying any of his statements; nor for assuming that, the paint being useless and rusting started, the rusting would not continue more or less rapidly.

Mr. Carpenter states that "there were two rivet heads which evidently had never received any paint and had not been in contact with mortar; these heads looked exactly like those of newly made

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* *Engineering News*, December 1st, 1910.

† *Engineering Record*, November 5th, 1910.

Mr. Thomson. rivets, the blue scale on them being perfect, and no touch of rust showing." And yet, after 14 years, there was enough deterioration to destroy the paint and show rust in so many other places. Most people will assume that he was mistaken in thinking that the mortar had not been in contact with these rivet heads, and doubt the other conclusions of his brief inspection.

In one of the columns, in the joint used for leveling up, there were several shim plates which showed very strong evidence of rust, as did the interior of the column at the same place.

One object of the paper was to bring out discussion regarding substances which would keep air and moisture from steel. Oil paints are short-lived. If concrete is used, care must be taken to make it waterproof and air-proof, and also proof against the passage of electric currents. It is known that a mortar consisting of 1 part of Portland cement and 3 parts of sand does not fulfil these conditions, and even a 1:2 mixture is not any too rich in cement to fill the voids. It is also known that a "dry" mixture of concrete will not answer.

Mr. Carpenter attempts to prove that the writer's observations, from the seventeenth floor down, from day to day, were not correct, while his one visit to the sixth floor was sufficient; he also thinks the writer was wrong in stating that "wherever the spaces between the brick and steel were filled with Portland cement mortar, there was no rusting, but, wherever the mortar did not fill such spaces completely, rusting had begun."

Mr. Carpenter says that the tops of the floor-beams "were rather generally rusted," and he thinks that those surfaces were probably not painted. He also states that "no pitting or formation of rust scale was observed." From which one must conclude that he did not see the columns of which Mr. Nichols published photographs.

He states that the worst rusting was in the northeast column. As the worst column was below the roof of the adjoining building, it is doubtful if he could have seen it on the day of his hurried inspection. Everybody agrees that one side of this column showed decided evidence of rust,* while the other three sides were in good condition. In other words, the side which was protected only by paint was in very bad condition, while the three sides which were protected also by brick and mortar were in good condition. He also thinks it possible that, in the case of the worst rusting, "the brick and mortar work was of the poorest quality."

He admits that "the paint on outside surfaces, where the mortar did not come in contact with them, was not invariably found in good condition by the other observers," and thinks that "water probably obtained access to such surfaces."

* As shown on the photograph in *Engineering Record*, November 5th, 1910.

Mr. Thomson.

He objects to the writer's statement that there was no rust where the mortar was in contact with the steel, and yet he says, "Where mortar came in contact with painted surfaces, the oil vehicle of the original paint film was generally removed, leaving only the dry pigment adhering to them. There was plenty of this dry pigment on such surfaces * * * and much good paint film."

In short, after stating "that his observation and conclusions were so contrary to those of Mr. Thomson," he practically proves the correctness of the writer's observations and conclusions, by asserting: (1) That the paint was of very little service, and cited cases where he did not think there ever had been any used; (2) That the paint was gone in many places; (3) That he differed with the Board of Fire Underwriters as to what kind of paint had been used; (4) That where he removed the mortar, he found the steel still covered with pigment, etc.; (5) That the rusting was worst where the brick and mortar were poorest—probably porous.

Mr. Carpenter is mistaken in thinking that the engineers of the New York Central Railroad were the first to discover that concrete and oil paints do not work well together. He is also wrong in thinking that 1 in. of mortar is sufficient protection.

It is to be regretted that he did not read the paper more carefully before contradicting it so flatly. The writer did not infer that the building was on the verge of collapse; as a matter of fact, he thought it a great pity that the steelwork of the Gillender Building had not been cleaned, re-erected, and properly protected against moisture, etc., instead of being turned into scrap.

Mr. Carpenter says that he has been well sustained by other observers. The writer also has been sustained by every one with whom he has discussed the matter.

The reference by Mr. Lavis to the article in *Engineering News* was made at the request of the writer, as it is very interesting. Whether the result quoted was due to the mortar being porous, or containing some foreign substance, is not known.

Mr. Purdy's remarks have been borne out in many cases which have come under the writer's observation, where steel taken out of concrete has been cleaner than when put in. Mr. Purdy is correct in saying that "Portland cement is an almost perfect protection for steel." What is wanted is to be able to strike out the word "almost," by improved methods, or the addition of some other substance.

Mr. French's remarks are worth careful study, as they are the results of practical experience and sound judgment.

Mr. Gardiner's discussion, citing cases where anchor-bolts have been taken out in good condition, is also interesting. Other cases are on record where anchor-bolts have been destroyed by electrolysis, the brick piers themselves being badly cracked by the process. His description

Mr. Thomson.

of thin reinforced concrete walls shows the great danger of such construction where the concrete is not thick enough to keep air, moisture, or electric currents from the reinforcing metal.

The writer, not having used paraffin for steel protection, will make no comment on it.

To come back to the Gillender Building, the writer believes that the steelwork received three coats of paint of standard grade, and that they were thoroughly applied. The universal opinion is that, after 14 years the paint on these columns, encased in brickwork, was found to be absolutely useless as a protection. Obviously, there was no practical method of replacing this lost coating. Most people will admit that in such a case rusting will continue, and that there is still very much to be learned regarding the protection of steel from rust and electrolysis.

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TRANSACTIONS

Paper No. 1184

THE FAILURE OF THE YUBA RIVER DÉBRIS BARRIER, AND THE EFFORTS MADE FOR ITS MAINTENANCE.*

By H. H. Wadsworth, M. Am. Soc. C. E.

With Discussion by Messrs. William W. Harts, W. C. Hammatt, T. C. Atwood, and H. H. Wadsworth.

The structure on the Yuba River which has been commonly known as "The Barrier" was one of those forming the system of works to restrain the movement of hydraulic mining débris down the Yuba and into the Feather and Sacramento Rivers. Some portions of this system are now in operation, and others are in course of construction.

A general description of the project and of its several constituent parts, including details of construction and photographs, may be found in a paper, entitled "The Control of Hydraulic Mining in California by the Federal Government,"† by William W. Harts, M. Am. Soc. C. E., Major, Corps of Engineers, U. S. Army. The reader is referred to this paper for a history of the experiments leading up to the design and construction of this barrier.

The barrier failed on the night of March 17th and 18th, 1907, during the unprecedented flood that set new standards as to flood heights and stream flow, of the Sacramento River and all its tributaries, for engineers dealing with reclamation and flood control prob-

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* Presented at the meeting of November 16th, 1910.
† *Transactions*, Am. Soc. C. E., Vol. LVII, pp. 20-26.

lems. This flood forms the subject of a paper, by Messrs. Clapp, Murphy, and Martin, entitled "The Flood of March, 1907, in the Sacramento and San Joaquin River Basins, California." *

The writer's connection with the Yuba River works began at about the time the contract for the second step of the barrier was let. Under the direction of the California Débris Commission, his efforts, in so far as that structure was concerned, were directed toward maintaining and safeguarding it. Notwithstanding its unfortunate destruction, engineers still manifest considerable interest in the barrier, as well as in other features of the system of débris restraining works. This fact, together with a special request of the Board of Directors of the San Francisco Association of Members of the American Society of Civil Engineers, has induced the writer to prepare this paper, in the hope that something of advantage to the Engineering Profession may be gained by its presentation.

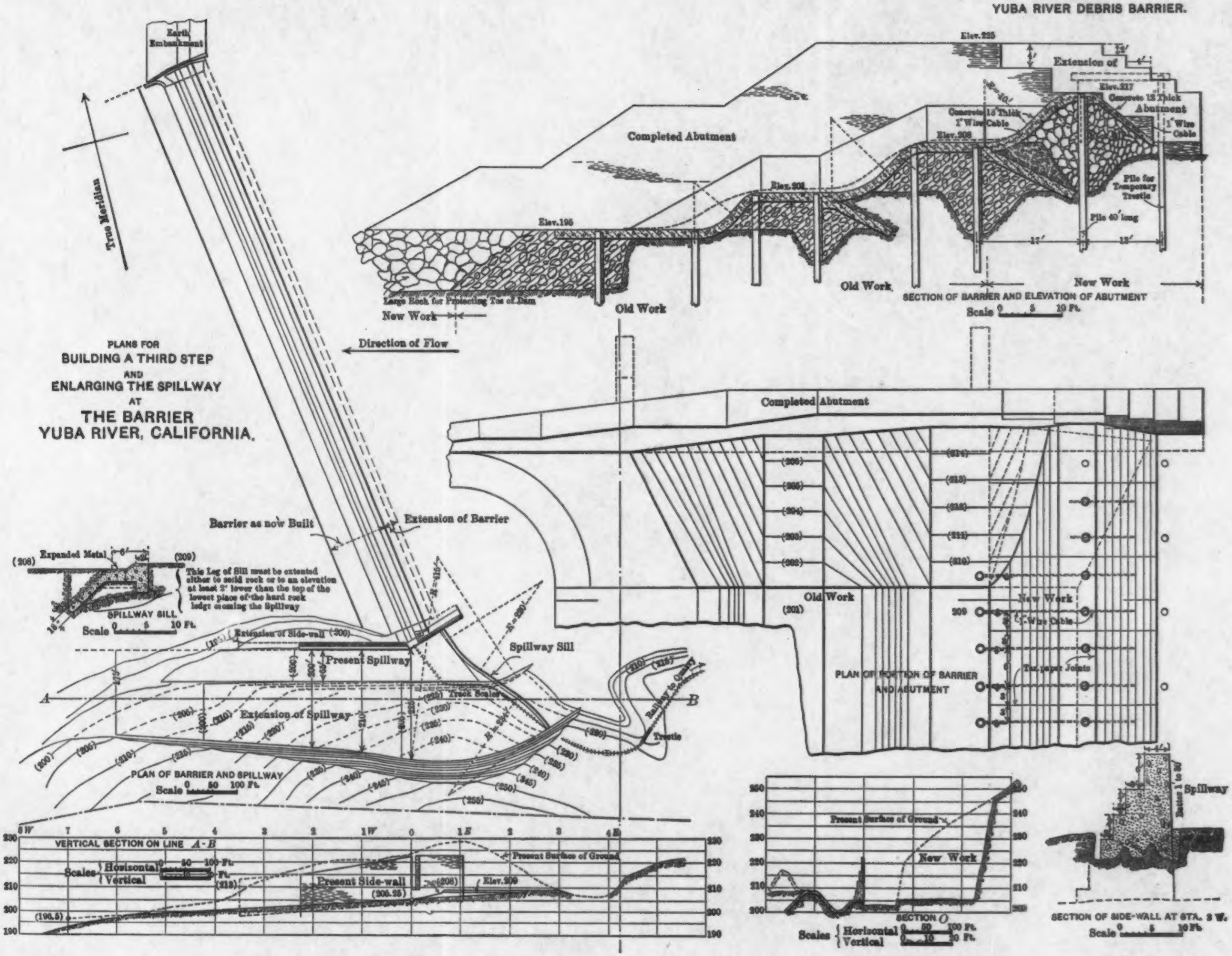
As stated by Major Harts, two steps of the dam were built, 6 ft. and 8 ft., respectively, making a total of 14 ft. above what was the bed of the river when the first step was built. The first step was backed up by tailings on the occurrence of the first high water after its completion. Likewise, during the first flood following the completion of the second step, tailings banked it up to its crest, and subsequent high waters carried large quantities of gravel over the dam, which caused considerable wear on the concrete surface. At the same time, the water, with its increased velocity, due to its drop, caused extensive scour at the toe.

In 1906, it was decided not to raise the dam by an additional step, but to devote all the energy possible to excavating a spillway and constructing the side-wall for it, and to increasing the output of the quarry to a maximum for use in toe protection.

The Yuba River, the flow of which ranges from a minimum of about 400 sec-ft. in summer to a maximum of 125 000 sec-ft. during extreme floods, maintained, during May and June and well on into July, 1906, a flow of between 10 000 and 20 000 sec-ft. On account of the arrest of the passage of débris by the dam, which would continue to be effective, though in lessening degree, until the accumulation above it had been built up to a slope approximately parallel to the

* *Transactions*, Am. Soc. C. E., Vol. LXI, p. 281.

PLATE XXXII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXI, No. 1184.
WADSWORTH ON
YUBA RIVER DEBRIS BARRIER.



former slope of the river bed (about 19 ft. per mile at this point), the flowing water, thus relieved of its load above the dam, was able to pick up a new one below and scour out a channel down stream from the dam sufficient to prevent a water-cushion from forming there, which would have served as some protection against further undermining action.

Of the more than 5 000 tons of large rock placed at the toe of the barrier in 1905, comparatively little remained in sight by June of the next year, the scouring action having buried it in the gravel. The depth to which scouring action extended was in some places as great as 12 ft. The undermining of the gravel from behind the plank bulkheading of the first row of piles extended back under the dam irregularly, in some places as far as 4 ft. The surface of the river above the dam was 25 ft. above the lower part of the undermined face, but the fact that there was little or no evidence of seepage showed the density of this natural hydraulic fill. During the summer of 1906 this cavity was filled with rock placed by hand, and about 3 500 tons of large rock were added to the rock apron, the theory on which this work was continued being that, as the high-water periods during which excessive erosion occurred were separated by several months' time, it would be possible after each flood to restore the settled rock fill to grade by the addition of new material, and that this process could be continued until the barrier had been raised to its final height. On reaching this point, the spillway, as designed, would have sufficient capacity to carry the entire flow of the river except during a very few days each year.

How vital to the maintenance of the barrier the construction of the spillway was recognized to be is shown by the following consideration. The nearest down-stream point which would limit positively the depth of scour above it was at Daguerre Point Cut, 6 miles away, the sill of which was at Elevation 125. The concrete apron at the toe of the barrier was at Elevation 195. If, by reason of holding back the supply of gravel above, the scour continued below until a slope as flat as 8 ft. per mile up from Daguerre Point was reached, it would then have stood 36 ft. above the bed of the river. The projected height would thus have been reached, but by building downward rather than upward. Bed-rock in the old channel of the river is probably at about Elevation 140, or 55 ft. below the concrete apron of the dam.

During 1906, in addition to repairing the damage at the toe and placing the large rock previously mentioned, a spillway, 65 ft. wide (150 ft. wide at the entrance) was excavated, and a concrete side-wall for it, 320 ft. long, founded on solid rock, was built. The spillway and wall foundation required the excavation of 2 500 cu. yd. of rock and 8 300 cu. yd. of earth. A new railway track, of 25-lb. steel rails, 3-ft. gauge, and nearly level gradient, was constructed from the barrier to the quarry (½ mile), and cars, derricks, additional hoisting engine, etc., were acquired in order that in future the Government might save the expense of the long haul of contractor's plant when a change of contractors occurred.

The first step of the spillway afforded very little relief in floods, but it was capable of carrying the entire dry-weather flow, and would be of great service in constructing additional steps to the barrier, as the difficulties in making the closure and turning the water over the completed structure when the first, and to a much less extent, when the second step was built, would be avoided.

By the time the work of the season of 1906 had been completed the engineers in charge of the Yuba River work had become convinced that the attempt to increase materially the storage of débris by raising the barrier several additional steps, as planned, would be hazardous to the structure until a spillway of the full capacity finally contemplated had been constructed. It may be well to note that the usual risk to interests along a watercourse below a reservoir dam of questionable stability did not exist here, because at no time was any considerable volume of water impounded.

In designing the several Yuba River works, the maximum flow had been assumed at 125 000 sec-ft., which was from 25 to 50% greater than the probable maximum, as indicated by available records. This discharge, however, was nearly, if not quite, reached during the 1907 flood. This meant a depth of water of more than 7 ft. over the 1 225-ft. crest of the barrier. A flood of anything like this volume, however, continues for but a few hours, and a flow of one-quarter of that amount never continues more than a few days. The site of the spillway was a steep hillside, necessitating a much larger amount of excavation to give a cross-section sufficient to carry the desired flow of 20 000 sec-ft. below the level of the crest of the barrier than would have been the case could the barrier have been first built to its projected height. As

FIG. 1.—YUBA RIVER BARRIER, ON OCTOBER 4TH, 1905.

FIG. 2.—YUBA RIVER BARRIER AFTER FRESHET OF JANUARY, 1906.
WATER 1.4 FT. DEEP ON CREST.

the further movement of large quantities of gravel over the concrete surface of the dam, already backed up to the crest, was then known to be fraught with serious consequences, it was decided to widen the spillway, without materially raising its floor, and to build one additional step to the barrier, which would increase the depth of water in the spillway by its own height and, on account of the large flow through the spillway, would not be banked up by tailings to its crest, except possibly at its north or farther end.

In order that the extensive work contemplated might be done during the season of 1907, plans were prepared and a contract let muck earlier in the season than had been customary on previous contracts. On February 23d a contract was awarded for building a third step to the barrier, 8 ft. high, enlarging the spillway, extending both the spillway side-wall and the north abutment, constructing a sill across the spillway, and placing large rock at the toe of the barrier. The general plan for this work is shown on Plate XXXII. The approximate quantities were as follows:

Earth excavation	78 000	cu. yd.
Rock excavation	15 000	cu. yd.
Concrete	3 150	cu. yd.
Piles	210	
Lumber	5 500	ft. b. m.
Rock fill, including sluicing of sand and gravel	7 000	tons
Large rock for toe protection	5 000	tons
Wire cable (1-in.)	7 400	lin. ft.
Expanded metal	2 700	lb.

The approximate estimate of cost was $124 000.

Work was started at once. The contractor made arrangements with a water company for water, to be delivered at a point above the site of the work, which would give 100-ft. head; and a plant was partly installed for making the earth excavation of the spillway by using a jet and sluicing. The necessary stripping in the quarry was commenced.

From January 31st to February 2d there was a severe storm. The flow of the river, as deduced from depths on the barrier and in the spillway, rose to 80 000 sec-ft., and a large volume of gravel passed over the dam. The water continued to be too high to permit of a

critical examination of the structure, but its appearance, as viewed from either end, did not differ noticeably after this flood from that before. In fact, the rate of scour at the toe seems to have been greater at somewhat lower stages than at maximum flood stage, the reason being that the outlet channel from the pocket eroded from below the toe was of insufficient capacity to carry the flood without backing it up to a considerable extent, thus forming a water-cushion.

Had this February flood been the last of the season, as might reasonably have been expected, the barrier would probably have been still standing, with but little doubt as to its permanency, as the maintenance would have been a much simpler matter after the completion of the contract then in force. However, the disastrous flood already referred to, which was of greater volume than had ever theretofore been reliably recorded, occurred in March, and during the night of the 17th and 18th of that month about one-half of the barrier was swept away. The contractor's camp was not more than 500 ft. distant, but no one there knew of the failure until the next morning. Water marks in the vicinity showed that before failure the depth on the crest was 7.5 ft. at the south end and 6.5 ft. at the north end.

When seen by the writer, a few days later, the river-bed through the breach presented the same smooth gravel surface that had marked it before the barrier was started, with only one or two piles, having pieces of the wire rope anchorage attached, projecting above the surface, about 100 ft. down stream from the line of the dam.

Either of two causes may have been immediately responsible for the failure: first, the undermining of the structure by back-lash; or, second, the wearing away of the concrete surface of the apron and first step, 18 in. thick, thus permitting the rapid washing out of the rubble rock fill. There was not time, nor did the flow of the river diminish enough between the two floods of February and March, to permit of any addition being made to the rock fill at the toe of the dam, or of any repairs to the concrete surface.

Considering the conditions at the toe of the dam on the day before the failure, as reported by reliable witnesses, and the appearance of that part of the structure still standing, which adjoined the part washed out, the writer is convinced that the concrete surface for a considerable length was literally worn away by the great quantity of hard quartz cobbles and gravel which passed over it.

FIG. 1.—MAXIMUM SCOUR AT TOE OF BARRIER, SUMMER OF 1906.

FIG. 2.—EXCAVATION FOR SPILLWAY AND FOR FOUNDATION OF SIDE-WALL IN PROGRESS, IN SEPTEMBER, 1906.

Plates XXXIII to XXXVII show the conditions at the barrier during the summer and fall preceding, and the spring following the failure.

Some notes on the design of the spillway, as shown on Plate XXXII, may be of interest. The stepped form of the cross-section of the side-wall is due to the fact that it was originally designed with special reference to future enlargement to the requirements of a dam 14 ft. higher than that of the modified plan. The spillway was designed to carry 20 000 sec-ft. of water before any passed over the barrier. For different depths of water on the crest of the barrier, the total discharge of the river would be distributed approximately as shown in Table 1.

TABLE 1.

Depth on barrier.	Discharge over barrier.	Discharge through spillway.	Total discharge.
0	0	20 000	20 000
1	4 400	23 300	27 700
2	13 000	25 700	38 700
3	24 000	29 300	53 300
4	38 000	30 900	68 900
5	54 000	33 400	87 400
6	71 000	36 100	107 100
7	90 000	38 600	128 600

A comparison of these estimated capacities with the actual estimated flow of the river, as determined from gauge heights at the barrier, indicates that, had this spillway been constructed, water would have flowed over the barrier during the period from July, 1905, to March, 1907, on only 5 days in January, 4 days in March, 1 day in May, and 3 days in June, 1906, and on 4 days in January, 3 days in February, and 17 days in March, 1907. The depth on the crest of the barrier would have exceeded 1 ft. on only 4 days in January, 1906, and on 2 days in January, 4 days in February, and 4 days in March, 1907. It would have exceeded 2 ft. on only 2 days in January, 1906, and on 1 day in January, 2 days in February, and 2 days in March, 1907. Considering the fact that practically all the scour occurred when the depth on the crest was between 1 and 3 ft., it will be seen that, with the spillway completed, the period of scour would be limited to a very few days, even during such a flood season as that of 1907; and it should be remembered that that record had not been made when the spillway was planned.

The hillside through which the spillway excavation was to be made had a slope of about 1: 5 and was of very irregular formation. The south abutment of the barrier was founded on a ledge of hard blue rock, either trap or diorite, having a specific gravity of nearly 3.1. The outcropping rocks on the hillside consisted of boulders and the pinnacles which are characteristic of this region and which, below the surface, vary in structure from hard trap to soft chloritic rock or serpentine, and to decomposed rock and clay. When sinking drill holes in this formation a difference of 2 ft. in position would frequently make a difference of many feet in depth to hard rock, and even then there was no assurance that ledge had been reached. For this reason the exact location of the sill was left indeterminate. It was to be located as far up stream as a suitable foundation would permit. The crest of this sill, 2 ft. wide, was to be 8 ft. below the crest of the new step of the barrier. The concrete surface was then to have a drop of 1 ft., on a 45° slope, followed by a 3-ft. level surface. From this point the floor of the spillway was to have a gradient of 1.25 per cent. The plan of the spillway and the gradient were adjusted to give the greatest capacity for the least amount of excavation.

In determining the widths of the spillway at successive sections, the depth was assumed to be constant and the velocity was calculated by a formula which the writer found developed in a paper, entitled "The Velocity of Water Flowing Down a Steep Slope,"* by E. P. Hill, M. Inst. C. E. The formula was simplified by the writer to the form

$$V = \left[V_1^2 + \frac{1}{\varepsilon^{\left(\frac{V_H}{V_1}\right)^2}} (V_1^2 - u^2) \right]^{\frac{1}{2}}$$

where $V_1 = C \sqrt{r\,S}$, the usual formula for velocity in watercourses,

$V_H = 2\,g\,H =$ the velocity, due to gravity, of a body falling freely,

$u =$ the velocity of approach, and

$\varepsilon =$ the base of the Napierian logarithms $= 2.718$.

This formula is based on two assumptions: that the experimental values of C in the ordinary watercourse formula are applicable to high velocities; and that, within narrow limits, the hydraulic mean radius may be taken as constant at its mean value. The mathematical derivation of this formula is somewhat involved, but all the steps were

* *Minutes of Proceedings*, Inst. C. E., Vol. CLXI (1904-05), p. 345.

PLATE XXXV.
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WADSWORTH ON
YUBA RIVER DEBRIS BARRIER.

FIG. 1.—VIEW OF BARRIER IN NOVEMBER, 1906, LOOKING NORTH. SIDE-WALL OF SPILLWAY IN FOREGROUND.

FIG. 2.—VIEW OF BARRIER IN NOVEMBER, 1906, LOOKING SOUTH. SIDE-WALL OF SPILLWAY IN BACKGROUND.

FIG. 3.—PANORAMIC VIEW ON MARCH 28TH, 1907, AFTER THE DESTRUCTION OF THE BARRIER.

checked by the writer, and he believes that it gives safe results. The velocity of water flowing in a channel on a steep slope will, of course, continue to increase until the acceleration due to gravity is counteracted by the increased frictional resistance. When this point is reached, $V = u$, and the formula reduces to $V = V_1 = C\sqrt{r\,S}$, as it should.

That the applicability of this formula is not limited to slopes of small degree is shown by the fact that for high values of S, as for instance $S = 0.707$ (45° slope) or $S = 1$ (vertical drop), substituting numerical values for h and r, reduces the expression to the form $V = \sqrt{a + bu^2}$, in which a is but little less than $2gH$ and b is almost unity; that is, the value of V is very little less than $\sqrt{2gH + u^2}$, which would be its value were it influenced by gravity alone.

Applying this formula to the barrier spillway gives the necessary widths at successive points by the steps tabulated below. In laying out the spillway, these widths were departed from slightly for simplicity and for other considerations.

Depth of water above sill = 8 ft.,
Depth of water below sill (1 ft. drop) = 6.3 ft.,
Value of r (below sill) = 6 (constant through spillway),
Velocity of water at foot of sill = u = 10 ft. per sec.,
$S = 0.0125$; $n = 0.030$; then $C = 67.6$,
$V_1 = C\sqrt{r\,S} = 18.51$;
W = width of spillway.

TABLE 2.

Vertical distance below sill = H.	Corresponding horizontal distance.	V_H	$\dfrac{1}{\varepsilon^{\left(\frac{V_H}{V_1}\right)^2}}$	V	Area of section to carry 20 000 sec-ft.	W
0	0	0	0	$u = 10$	2 000	318
1	80	8.03	0.8295	11.89	1 685	268
2	160	......	......	(13.2)	1 525	242
3	240	......	......	(14.35)	1 393	221
4	320	16.06	0.4642	15.20	1 315	209
5	400	......	......	(15.8)	1 265	201
6	480	......	......	(16.25)	1 231	196
7	560	......	......	(16.65)	1 201	191
8	640	......	......	(17.0)	1 176	187
9	720	24.09	0.1848	17.29	1 155	183
10	800	......	......	(17.6)	1 136	181
16	1 280	32.12	0.0498	18.4	1 085	173
25	2 000	40.15	0.0066	18.5	1 082	172

The values of V in parentheses were not computed, but were taken from the diagram, Fig. 1, which shows the velocity curve.

In addition to the work for the protection of the barrier, already described, which was in progress, a change in the form of its concrete rollway surface was contemplated in connection with the repairs to that surface which had become necessary. When there had been but one step the water followed smoothly in its ogee shape, but when the second step was constructed the increased velocity at its foot caused it to leap over the upper curve of the first, so that, with its load of

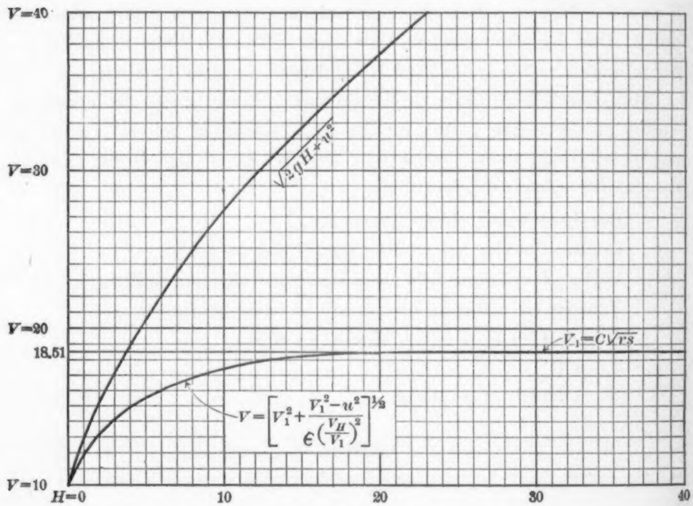

FIG. 1.

gravel, it struck the lower or reverse curve well down toward the apron. The impact of the water and gravel on the concrete doubtless greatly increased the wear on the latter. A uniform slope to the down-stream face would probably have carried the gravel down with less wear, but that form was not adopted originally because less weight was given to that fact than to the reduction in the dangerously high velocities which the steps would effect. To have transformed the stepped face to a uniform slope would have required an excessive amount of concrete.

FIG. 1.—LOOKING DOWN STREAM FROM THE QUARRY.

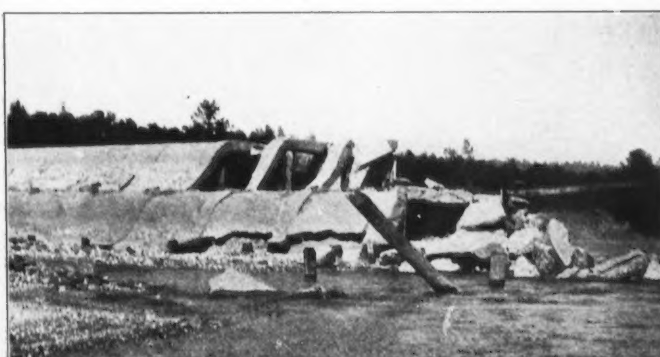

FIG. 2.—NEAR VIEW OF NORTH END OF BREAK.

FIG. 1.—CONCRETE APRON OF BARRIER WORN AWAY, EXCEPT SMALL PIECES PROTECTED BY PILES.

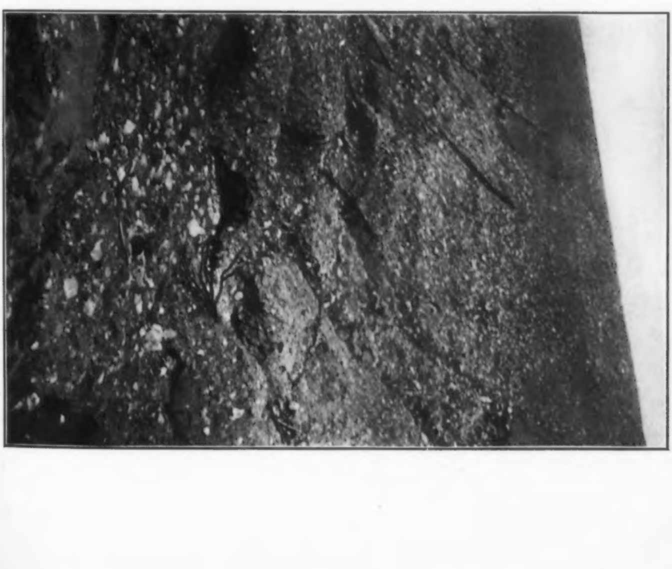

FIG. 2.—HOLES WORN THROUGH CONCRETE AT FOOT OF SECOND STEP.

A study of the path of the body of water as it leaves the horizontal portion of several succeeding steps, assuming an initial velocity of 8 ft. per sec., shows that, if all the energy acquired in each descent were retained, the radii of curvature of the convex portion of each step, from the top down, to be just in contact with the flowing water, would be approximately 2½, 20, and 34 ft., respectively. Assuming that 20% of the energy developed by the fall over each step is dissipated in friction, etc., the horizontal velocity of the water would still be such as to require radii of curvature of 2½, 16, and 25 ft., respectively, for succeeding steps.

In connection with repairing the concrete surface of the barrier, a modification of its form to one approximating that shown by the heavy broken lines on the section, Plate XXXII, was under consideration.

The destruction of the barrier and the decision to use the further available funds along lines which gave promise of greater efficiency in restraining the movement of débris than would the reconstruction of the barrier, put an end to further consideration of plans for its maintenance.

At present, 3 years after, the site of the barrier presents substantially the same appearance as it did a week after the failure, except that more of the impounded tailings have washed out from the portion still standing.

DISCUSSION

Mr. Harts.

WILLIAM W. HARTS,* M. AM. SOC. C. E. (by letter).—This barrier was one of a series of extensive works adopted on the Yuba River for the purpose of holding back the débris which had been dislodged by hydraulic mining and was later filling the channels of the navigable streams during each flood. The original design for this control was prepared by the California Débris Commission before the writer's connection with it, and has been described by him.†

After a number of unsuccessful attempts at dam construction in this locality, the writer was called on to design a barrier that would hold débris. There were several unusual conditions: First, the discharge of the river is variable, ordinarily extending from 600 or 700 sec-ft., and reaching 60 000 or 70 000 sec-ft., these higher stages lasting but a few days at a time. Second, the foundations were gravel and fine sand, intermixed with boulders, extending to great depths, on which any permanent structure would be built at considerable risk. Third, only a small portion of the total height could be built in any one season, as a portion when completed was necessarily subject to floods during the winter following, making the work of necessity one of successive steps, each of which would have to be completed in a single working season. Fourth, the cost could not be high, as the total amount available for the entire system was limited.

It occurred to the writer that the best solution would be to divert the river, during ordinary flow and in moderate floods, through a spillway which could be cut in the rock bank on the south side of the river, and construct in connection with it a rock-filled dam, held in place by piles and covered with a layer of concrete, so that the peak of the floods, usually of a few days' duration only, could be passed over the dam without more than slight injury, easily repaired each season. It seemed that in some such way only could a permanent dam be constructed at moderate cost at the site where required. If such a dam could be constructed strong enough in the first few steps so that the spillway need not be built until the structure had reached a considerable height, much spillway excavation in the rock could be saved. The plan adopted involved raising the dam to a height of about 22 ft., in three steps, the river flow to be carried through the rock spillway, which was to be large enough to accommodate 20 000 sec-ft., all water above this quantity passing over the crest of the dam. It was ascertained from the records that, with this spillway capacity, the dam would be used but a few days each season, the high-water wave being of short duration. In order to reduce the cost of construction, it was

* Major, Corps of Engineers, U. S. A.

† *Transactions*, Am. Soc. C. E., Vol. LVII, pp. 20–26.

determined not to commence the spillway until two steps had been finished. The first step withstood successfully the high-water stages of several seasons, and the second step had likewise passed through two flood periods without particular injury. It was expected during construction that the usual floods would be encountered each winter, and the information as to the river stages was relied on to indicate their magnitude and duration. Although the construction was attended with some risk, it was not an unreasonable one. It appears to be beyond question that, but for the unprecedented flood occurring after the cessation of the ordinary high-water stages and after work for the next season had begun, the plan would have been satisfactory. This unprecedented flood, as has been stated by the author, set a new record for high water on the Sacramento and Feather Rivers, and created great destruction elsewhere in that vicinity. This flood has been very fully described.* The author's description of the method of failure appears to have been analyzed correctly, but it is impossible to do more than surmise as to which method of failure was the predominant one. Mr. Harts.

Owing to the shortage of funds and the necessity for completing other portions of the débris system first, it was decided not to restore this work until the more important features lower on the river had been completed.

As sometimes occurs in connection with structures of this kind, there arose some of those unprecedented and unforeseeable conditions which occasionally derange and at times upset the most carefully laid plans. Although reasonable risks can never be entirely avoided by the hydraulic engineer, the measure of how far he may trust known local conditions in building unusual structures is one that can only be regulated by personal judgment and experience.

W. C. Hammatt, M. Am. Soc. C. E. (by letter).—In reading this paper the writer was particularly impressed with the inefficacy of the attempts to protect the toe of the barrier against scour, due to the double cause of erosion from the overpour of the water and the flattening of the slope of the stretch below the barrier by the removal of débris from the bed. It is believed that this might have been prevented by a method which the writer has applied with good results to structures of various classes. Mr. Hammatt.

In 1897 the writer had occasion to protect the footing of a masonry bridge abutment erected without piling on a gravelly bed at a point where a sharp bend of the river made it especially subject to scour. He placed a concrete apron, 16 ft. wide and 3 ft. deep, in front of the whole exposed face of the abutment, the upper surface being level with the river-bed. The apron was entirely detached from the foundation of the abutment, and was free to settle if there was any scour, as

* *Transactions*, Am. Soc. C. E., Vol. LXI, p. 281.

Mr. Hammatt.

shown by Fig. 2. As will be readily seen, the apron will settle and stop the scour before it can reach the bridge abutment.

This was so effective that the writer has subsequently used the same principle many times. He has found it very useful for weir dams in torrential streams, notably one in Los Baños Creek, Mercer County, California. In this case, however, the apron was constructed in sec-

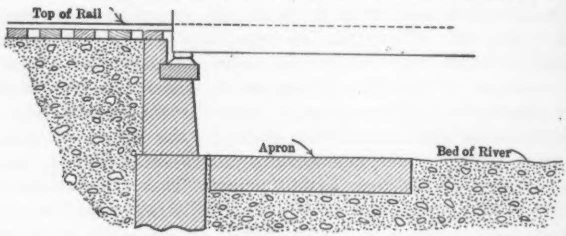

FIG. 2.

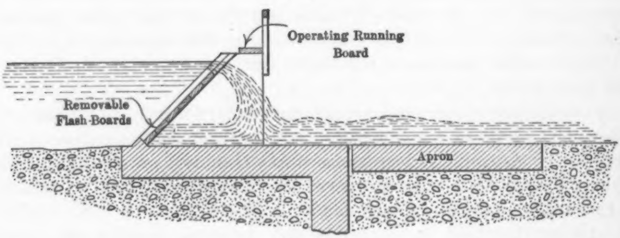

FIG. 3.

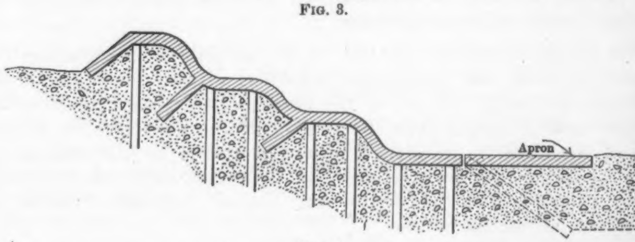

FIG. 4.

tions, or slabs, 16 ft. wide, 10 ft. long (in the direction of the dam), and 12 in. thick, as shown by Fig. 3. These slabs were entirely free to move independently of each other, in order to take care of scour in small sections.

It is believed that an apron of the same general nature would have given ample protection to the Yuba River débris barrier and prevented its final failure. As erosion took place in the river-bed below the barrier, the apron would drop gradually to the position shown by the

dotted lines in Fig. 4. After it had reached an inclination which rendered it inadvisable to allow it to sink farther, a new protective apron could have been constructed on the lower level, which, in turn, would have taken up the slope if the scour continued, thus forming a continuous rip-rap in front of the structure. Mr. Hammatt.

THOMAS C. ATWOOD, ASSOC. M. AM. SOC. C. E.—The prevention of scour at the toe of a dam such as described in this paper seems to be a subject about which there is considerable difference of opinion, and, consequently, it is open for discussion. Mr. Atwood.

It is not always easy to determine just what the primary cause of failure of an overfall dam is, whether it is through scouring at the toe or for some other reason, such as wear through the surface, which seems to have caused the failure of the Yuba River Barrier. Considerable scour occurred here, however, and might possibly have been prevented by methods similar to those used on the Alleghany and Ohio Rivers, where many large overfall dams, both movable and stationary, have been maintained successfully. Ledge is usually too deep to use as a foundation, so the dams which have been built by the Government to aid navigation are founded on the river gravel. The Government engineers have tried a number of schemes for preventing scour, all of which contemplate a flexible protection of stone below the dam. This will follow the surface of the gravel down, in the event of scour, until a condition of permanence is reached, and so protect the dam from being undermined.

The standard design now used consists of a deep crib, filled with stone, placed against the down-stream side of the dam, and reinforced by a triangular prism of heavy rip-rap on its down-stream side. The crib is usually about 20 ft. wide and 13 ft. deep next to the dam, its deck sloping upward about 2 ft. so that it is about 15 ft. deep at its down-stream side.

It is stated by Mr. J. W. Arras, United States Assistant Engineer, that:

"This system of crib and stone protection at the toe of the dam has been thoroughly tried out in this district during the past 7 or 8 years, both in connection with movable and fixed dams, and especially along the down-stream edges of bear-trap gates which at times are down for several days, passing their full section of water at velocities of 15 miles per hour or greater. Under such circumstances, the scour below bear-trap gates has frequently reached bed-rock at a depth of more than 40 ft. below low water, yet, in no case has the stability of the main structure or protection crib been threatened. The upward inclination of the crib has invariably tended to divert the scouring effect to a safe distance beyond the down-stream edge of the crib."

A slightly different method of protection was adopted for the two 72-in. steel pipes through which the principal water supply of the City of Pittsburg is carried across the Alleghany River.

Mr. Atwood. These pipes were laid side by side, encased in concrete, and protected from scour by rip-rap. The rip-rap was prevented from rolling away by piles, the piles being held together by waling pieces running up and down stream. In this case it was anticipated that scour might be caused by an ice jam.

On this same work the prevention of scour by giving the water an upward direction was tried at the end of a 48-in. drain which at times ran half full at a velocity of 10 ft. per sec. and discharged with a much higher velocity down a slope of 1:2 to the low-water level of the river. The toe of the concrete slope was curved so as to give the water an upward direction. To prevent the water from causing scour, there was no other protection than this upward turn at the mouth of the drain, and, on a number of examinations during a period of about two years, no scour was found. There was always a tendency for the water to form an eddy, thus bringing gravel up against the concrete rather than carrying it away.

Mr. Wadsworth. H. H. WADSWORTH, M. AM. SOC. C. E. (by letter).—The writer did not describe in detail the construction of the débris barrier, but, in addition to presenting its general plan (after the erosion of several seasons had taken place), simply referred to a previous paper which contained such detailed description; evidently Mr. Hammatt did not turn to the paper mentioned, and this appears to be responsible for his criticism. Below the lower row of piles of the apron a concrete extension of the latter was built on the river-bed, but not to as great a distance as shown on Fig. 4. In addition to this, the apron, as well as the upper portion of the structure, was constructed of blocks, moulded in place, 10 ft. long, between the narrow strips directly supported by the piles. Embedded in these blocks there were wire cables, designed to act as hinges, which would allow the blocks, when undermined, to fall into the cavity, substantially as shown by the dotted lines in Fig. 4.

No attempt was made to construct new concrete work in the eroded river-bed; but this space was filled as rapidly as possible with hard quarried rock, which proved to be much more resistant than concrete to the wear of the gravel. As pointed out in the paper, the quick succession of severe floods prevented the necessary increase in the rock fill; and the complete wearing away of the 18-in. thick concrete cover completed the destruction.

Mr. Atwood's suggestion for the protection of the dam against undermining by scour, namely, a flexible apron of stone below it, is precisely what was adopted.

The slope of the river-bed, at this point about 18 ft. per mile, with the tendency to flatten rapidly when the heretofore constant supply of gravel was cut off by the construction of the barrier, produced a situation very different from that on navigable streams, and rendered many precedents inapplicable to the problem.

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TRANSACTIONS

Paper No. 1185

THE ARCH PRINCIPLE IN ENGINEERING AND ESTHETIC ASPECTS, AND ITS APPLICATION TO LONG SPANS.*

By C. R. Grimm, M. Am. Soc. C. E.

With Discussion by Messrs. Max M. Miller, Leon S. Moisseiff, Fr. Engesser, R. Krohn, R. S. Buck, Ernst Jonson, Gustav Lindenthal, Paul Chapman, and C. R. Grimm.

The object of this paper is to present some suggestive designs for a bridge with several spans accommodating railroad and street traffic across a wide river, the channel span to be approximately of the greatest length thus far used in practice, so that simple trusses are out of the question.

Much has been written on the subject of long-span bridges, but it is far from being exhausted. Apparently there is yet much to learn regarding the construction of great bridges, and a thorough discussion of designs will bring out facts of undoubted value.

Girders and trusses, if acted on by vertical loads in their planes, can be divided into two distinct types: one including all those having vertical reactions, and the other those having inclined reactions. The second type represents the arch principle, which does not recognize any particular form of chords, but depends on the conditions of the supports. Thus, for instance, a girder or truss with parallel and horizontal chords is still governed by the arch principle, if the plane of contact of the supports is inclined.

* Presented at the meeting of November 2d, 1910.

While the first type, with vertical reactions, is properly used for very great spans, the second type is not economical for ordinary lengths, but is most suitable for such spans as are here under consideration; in fact, it is the only type to be considered for the maximum length of span which is practicable.

The cantilever truss, which is a notable example of the first type, will first be considered. The writer does not wish to say that, for a very long span, such a truss should never be built, because there may be isolated cases where it would be acceptable, but he does say that, on general principles, the cantilever truss is not by any means the most desirable of the many forms which may be designed for very long spans. If one insists on great rigidity and, comparatively speaking, on small deflections, and especially on economy, one must look for other trusses; the advantage that the cantilever trusses can be erected without falseworks is shared by other forms. Still another point to be noted refers to the secondary stresses to which trusses of every kind are subjected. In a cantilever truss it is particularly that part above and adjacent to the pier which is susceptible to severe secondary stresses, and, quite generally speaking, the selection of a truss should be made with due regard to these stresses. Wherever high secondary stresses may be expected (and also in doubtful cases) the designer should take account of them. The assumption that, in such cases, this matter is settled by the simple expedient of a little reduction in the amount of the unit stresses, may be convenient and comfortable, but it is certainly quite insufficient. Further, there is no doubt that the designer of a bridge of any kind is obliged to give it a satisfactory appearance, but the most that can be said of a cantilever bridge is that the configuration of its trusses may be designed in such a manner as to be inoffensive.

Another type to be considered is the continuous truss, which may be built if a sound rock foundation can be had. Having naturally a very great mass for a long span, it would be exceedingly sensitive to the displacement of its supports, and therefore great care should be taken in building its masonry, so as to avoid a large surplus of metal to meet any possible changes in the stresses. The secondary stresses in a continuous truss run rather high, especially in those parts which are over the supports. The tonnage of steel required is not particularly attractive, if compared with others, but it is superior to a cantilever

truss in point of stiffness and deflection, the latter being considerably smaller than in a cantilever truss. From an esthetic point of view, the continuous truss is just as difficult to treat as the cantilever truss.

There are still other forms from which the designer may select. For example, he may choose a truss having four points of support, in connection with wire cables or chains, and may fasten the ends of these to the ends of the truss so as to produce vertical reactions; but, whatever he may choose in this line will fail to give the desired results. The satisfactory solution of the problem points in some other direction.

Trusses of the second type, with inclined reactions, will next be considered. These are represented by suspension and arch bridges, and show a multitude of variations; they differ in essential details and in their relations to statics; and, if they are statically indeterminate, they share in a peculiarity which is common to all such structures. Apart from the fact that the analysis of their stresses is derived from the same point of view, the run of their stresses is more uniform and does not show such violent changes as are sometimes observed in statically determinate structures, a fact which may be of practical value.

A suspension bridge would solve the problem, provided great care was taken in its design as a railroad bridge, but the writer does not consider it the best solution. Skilfully designed, the bridge proper shows economy and has a pleasing appearance, but it also has disadvantages. The tonnage is influenced considerably by the anchor chains and anchorages, and particularly by the towers and the general stiffness. Further, it is to be noted that the effects due to temperature changes and yielding of the anchorage masonry, and also the deflections, are considerably greater in suspension bridges than in arches. It is very difficult to inspect the anchorages, which is a serious drawback, as the safety of the bridge is dependent on them, and the anchorage masonry is a very costly item.

A suspension bridge with a hinge at the center of the span is rejected, as it shows excessive deflections and a lack of stiffness, which are obstacles to fast-running trains. Continuous trusses are preferred on account of their stiffness, a quality which is valued in a truss as well as in a floor system.

Attention is now called to arches. It is somewhat strange that these bridges have never been as highly developed in America as other

forms of bridges. It does not appear to be necessary to discuss in detail the various forms of arches which are practically possible; on the contrary, some general statements will suffice. Spandrel arch bridges are excluded from consideration, for technical and esthetic reasons, and also the three-hinged arch, as it has the same objectionable features as the suspension bridge with a center hinge. Further, any arch which throws the thrust against the river piers must be excluded.

The two-hinged arch rib deserves very careful consideration, provided its form is properly chosen and it is given the necessary depth, as it is a remarkably stiff and safe structure, with small deflections, only influenced moderately by temperature changes, and therefore well suited for railroad purposes. Arch bridges of very long spans are more economical than other truss bridges, which is well shown by the crescent arch. Moreover, this rib, if of great depth, is a favorable truss in regard to secondary stresses which, as stated before, should be given due consideration before a particular truss is selected. In the present case it would be admissible, for the calculation of secondary stresses, to assume the moments of inertia of the web members equal to zero, so that the moments of two adjacent chord sections are equal to each other. On account of the points just stated, the crescent rib is selected as being a very fit type for the purpose, not merely for technical, but also for esthetic reasons, which will be shown later. This statement does not imply that other truss types are unworthy of study. The engineering features of the subject will be taken up first, and then some remarks will be given on the esthetics of bridges.

The writer has made estimates of weights for bridges of widely different designs, three arch bridges, a cantilever, and a suspension bridge. It is obvious that these are, of necessity, only approximate, as exact estimates can be based only on complete designs. These estimates are naturally governed by the same conditions, but, under the present circumstances, as many points, otherwise important, cannot even be touched, these conditions will be stated quite briefly.

The bridges are supposed to be of nickel-steel throughout and to accommodate two tracks for steam railroad service, the remainder of the floor being intended for other traffic. Each bridge has a central span of 1 800 ft. between end supports, and two shore spans, each 540 ft. between end supports, with two lines of main trusses

85 ft. from center to center. The main panels are from 90 to 100 ft. long, and are subdivided where practicable. The railroad stringers are estimated for the wheel concentrations of *E*-80, and each of the other stringers for a uniformly distributed live load of 2 500 lb. per lin. ft. The assumed live load for the main trusses is a uniformly distributed load of 16 000 lb. per lin. ft. per span, and of infinite length, and to be cut into sections, where necessary, to obtain the maximum stresses. The effects of dead and live load, impact, braking forces, wind pressure, change of temperature, and secondary stresses have been considered. For the main trusses, a limit of stress of 30 000 lb. per sq. in. has been assumed, and properly reduced for compression members, covering the stresses due to dead and live load, impact, and temperature; and for a combination of all the stresses previously mentioned, a limit of 37 500 lb. per sq. in. The stresses in the floor, suspenders, and posts outside of the main trusses, are supposed to be at least 20% less than the above limits. For the suspension bridge the stresses in the cables are assumed to be 60 000 and 75 000 lb. per sq. in., corresponding to those for nickel-steel. These unit stresses are immaterial, as the comparative bridge weights are the objects sought.

Each of the three forms of arch bridges to be considered, called *A, B* and *C,* Plate XXXVIII, has each line of trusses arranged as follows:

A.—Three crescent arch ribs, all three ribs coupled;

B.—Central crescent arch rib and two simple side trusses with horizontal bottom chords, all three trusses coupled;

C.—Two cantilever side trusses, each 940 ft. long, carrying a crescent arch rib of 1 000 ft. between end hinges.

Each of these three structures is statically indeterminate in the first degree, and each is assumed to have fixed hinges on the shore masonry and roller shoes on the piers, so that the thrust is delivered at the shore instead of at the pier, an obvious and great advantage. The adjacent ends of the trusses over the piers have a common hinge, or have separated hinges, but in either case a common roller shoe. The small horizontal force due to the frictional resistance at the roller shoes may be disregarded.

In Bridge *A* the rise of the bottom chords of the river and shore trusses above the springing line is 250 ft. and 40 ft., respectively,

and the depth of the trusses at their centers, 110 ft. and 80 ft. The clear height above high water is assumed to be 150 ft. for a distance of from 1 200 to 1 300 ft. Both chords of each truss are parabolic. The floor consists of floor-beams and stringers, and its loads are transferred to the main trusses, partly by suspenders and partly by vertical posts. Provision is made for a wind bracing with wind chords in the plane of the floor, and wind bracings between the bottom chords of each span, also vertical sway bracings at every panel point. These bracings, together with two main trusses, form a truss in space; they make the structural system complete and stiff, and, besides, they have the advantage of giving the construction a lighter and better appearance.

All questions relating to wind forces are more or less problematic, but they should not be made more so by comfortable assumptions which are not free from criticism. The effect of the wind force on such a large structure is very important, and, as the overhead bracing in this case is in a curved plane, computations can and should be used which will allow one to judge of the axial stresses, not only in the chords, but also in the web members of the trusses. Bending stresses due to wind force are a secondary consideration.

The general character of the 1 000-ft. and the 540-ft. arch ribs is the same as that of the 1 800-ft. rib in Bridges *A* or *B*.

The trusses of the deck spans in Bridge *B* have a supposed depth of about 120 ft., and the cantilever trusses in Bridge *C* a depth of about 220 ft. over the piers.

It is further assumed that the cantilever bridge with vertical reactions has a suspended span of about 700 ft. and a height of trusses over the piers of about 300 ft., while the suspension bridge has stiffening trusses with parallel chords, but the end spans are not suspended from the cables. The dip of the latter is 250 ft.

The structural work for all bridges is supposed to be of simple design, and to conform to the best practice of to-day.

The estimates of the probable weights of these five bridges give the following results:

Cantilever bridge	70 000	tons.
Suspension bridge	60 000	"
Arch bridge *A*	53 000	"
Arch bridge *B*	45 000	"
Arch bridge *C*	45 000	"

PLATE XXXVIII.
TRANS. AM. SOC. CIV. ENGRS.
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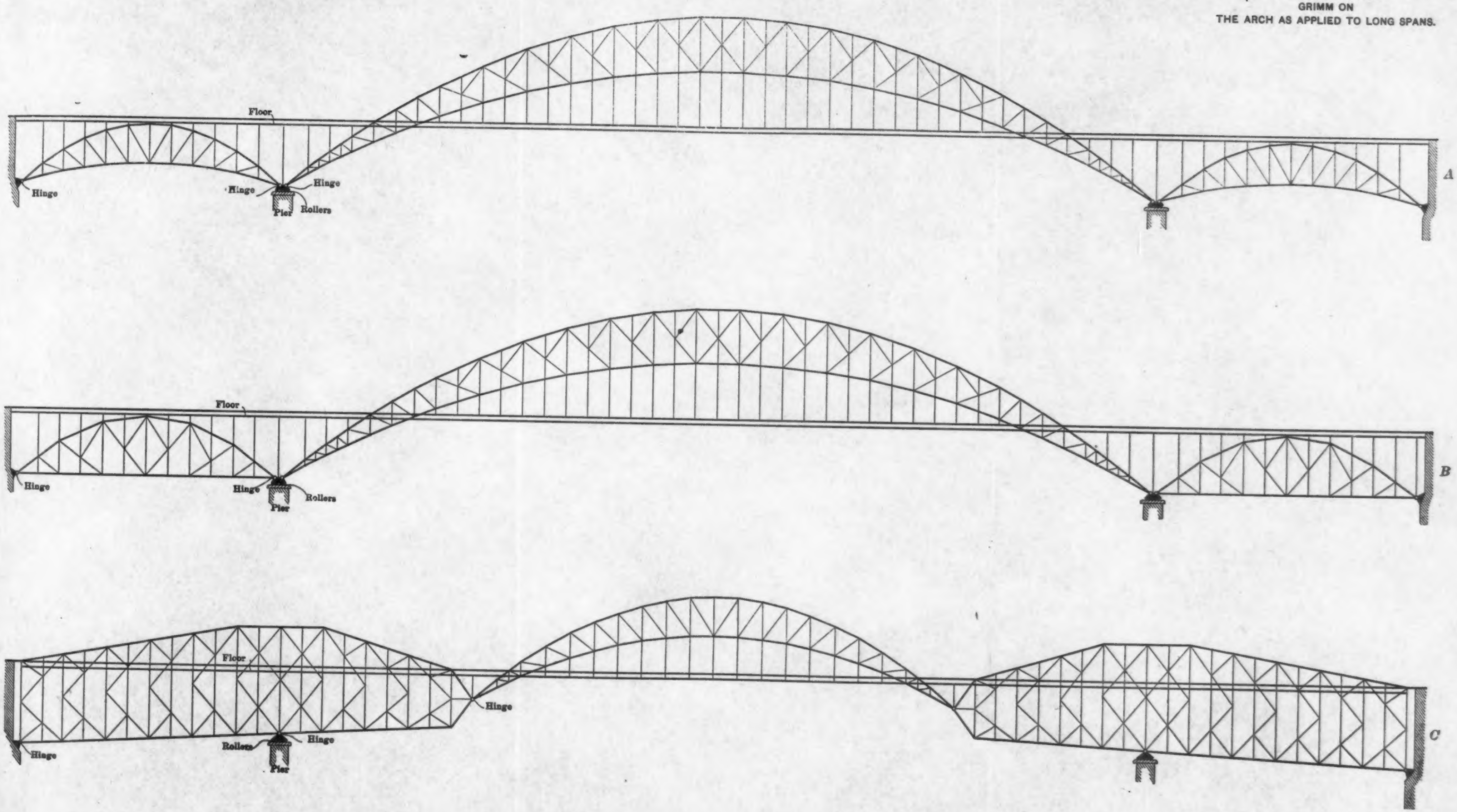
GRIMM ON
THE ARCH AS APPLIED TO LONG SPANS.



As might have been expected, the cantilever bridge is the heaviest. This tonnage of steel required for a cantilever bridge is excessive, and an explanation of this fact is found in the cantilever principle itself, as its use involves a very crude way of controlling great forces.

The suspended structure of a suspension bridge is an economical construction, but when it is considered that anchorages, anchor chains, and particularly gigantic towers more than 400 ft. in height are required to enable the structure to do its work, it is not surprising to find most of the economy in steel wiped out. In any case, a high degree of efficiency and safety will cost very dearly.

Comparing the weights per linear foot of the cantilever spans with vertical reactions with those of the side spans in Bridge *A* it is found that they amount to 25 tons in both cases, but this weight does not include the influence of the anchorages and tower footings of the cantilever spans or the truss bearings in Bridge *A*. The economy of the latter consists in the weight of the central span, which is 24 000 tons without truss bearings. The writer is of the opinion that, owing to their massiveness, the shore spans in Bridge *A*, although their length compared with that of the river span is as 3:10, harmonize perfectly with their function of carrying vertical loads and a great thrust. For a particularly heavy bridge such as this one, an advantage is gained by building twin trusses instead of single trusses for the short spans, which would facilitate the work in the shop and in the field.

It can be seen at a glance that the weight of Bridge *B* must be less than that of Bridge *A*, because, in the former, the thrust is taken in the most direct way by the horizontal bottom chords of the side spans.

The weight of Bridge *C* is accounted for by the economy of the arch span, estimated at 9 500 tons, and the combined influence of this weight and the thrust of the arch on the weight of the cantilever trusses, the configuration of which, naturally, also plays a rôle. A 1 000-ft. arch and short cantilever arms insure to this bridge considerable stiffness with moderate deflections, and if the designer succeeds in giving the cantilever trusses an inclination downward toward the shore, so much the better.

In actually designing such bridges, very thorough consideration should be given to the depth of the trusses; and an investigation should be made of the ratio of length between shore and river span and between cantilever arm and suspended arch, from both economical and

esthetic points of view. The writer's principal aim consists in laying before the reader the principles involved in these structures, rather than their weights.

The possibilities of arched steel ribs are far-reaching, and do not depend on the fact that special brands of steel may be used in their construction. It would not be surprising if an arch bridge of suitable design was easily victorious in competition with a stiffened suspension bridge having a main span far exceeding 1 800 ft.; but a discussion of such large spans, together with their erection, is beyond the scope of this paper.

The stability of the 1 800-ft. central span against wind pressure has been examined. Under the assumption that the two trusses of the unloaded arch, two sets of suspenders and posts, and a solid floor 10 ft. deep are exposed to the action of a horizontal wind force of 50 lb. per sq. ft., the total pressure was found to be about 2 400 tons and the resisting moment about two and one-half times greater than the wind moment. The stability of this span is further increased in no small degree by its anchorage to the piers and its connections with the end spans.

The safety of a bridge, being of paramount importance, deserves the most thorough examination from all points of view. The safety of a suspension bridge has been referred to as being dependent on the fixity of its anchorage masonry, and, in any case, that such a bridge is far more sensitive to a yielding of its supports than an arch bridge. Some suppositions will now be made which may appear extraordinary, but which the writer thinks will bring out the point concerning the effects of yielding supports. Let it be assumed that the depth of the 1 800-ft. rib in Bridge *A* is changed to one-tenth of the span, that is, 180 ft. at its center, and, further, that its form is selected so as to correspond to the moments, but that no essential change is made in the weight of the span. If, in this condition, the abutments would yield to the extent of reducing the thrust to zero, so that the trusses of all three spans would act with only vertical reactions, even then the central ribs under their own weights would survive the injury, but by stressing the steel nearly to the elastic limit, the shore spans, of course, suffering far less, or nothing at all, as the case might be. These spans are intended to carry a great thrust in addition to their own loads, and are therefore abundantly able to take care of themselves, even with

vertical reactions exclusively. Although the reduction of the thrust to zero may be improbable, its realization, nevertheless, is within the range of possibilities, for example, by an earthquake. Similar remarks hold true for Bridge *B*.

Under like assumptions and circumstances, a suspension bridge would be doomed to destruction long before the pull in the anchor chains reached the zero value. The point the writer wishes to make is that the safety of a suspension bridge against the consequences of any pronounced yielding of the masonry is incomparably less than that of an arch bridge with extra deep crescent ribs.

In case of severe injury to the shore masonry, bridges with very deep arch ribs also show a far greater safety against collapse if compared with common cantilever bridges or spandrel arches. The peculiar configuration of these latter trusses is irrational when it is considered that it shows the least depth at its center where it should be a maximum for any reduction in the thrust; and, of course, the greater this reduction the greater is the danger from excessive stresses. Deep crescent arches in any of the bridges, *A, B,* or *C,* meet in a natural way the conditions of increased safety, in contradistinction to the suspension and common cantilever bridge and the spandrel arch.

Before concluding this part of the paper it is necessary to refer to the manner of erecting the central spans of arch bridges. The smaller spans in Bridge *C* can be erected as guyed cantilevers, but the writer is of the opinion that the erection of the longer span is best effected on falseworks, for as many end panels as advisable, and as a guyed cantilever, if necessary, for the remainder of the span. Should it be found impracticable to carry the end panels of the longer span on falseworks, then the ribs could be erected as guyed cantilevers, or the construction of more than two trusses might be considered, as it would reduce the weight of the trusses and ease their erection. Convenient places of anchorage may be found in the heavy end spans.

Although the erection of an 1 800-ft. arch span can be effected successfully, it is, nevertheless, a very serious problem, and connected with risks great enough to make extraordinary means appear to be a necessity. On this account the writer would like to have a discussion of certain features in a design—provided they are permitted as proper—which are intended to reduce greatly the difficulties and risks connected

with the erection of such a large span, and at the same time insure other advantages.

Assume an arched truss in connection with a wire cable as a permanent carrying member, the ends of which are fixed in the same manner as in a suspension bridge. In such a case it is within the range of possibilities that the slackening of the cables will expose the truss to the danger of overstressing; but, if means are taken to remove this danger entirely such a design may be considered as admissible. For instance, the difficulty may be overcome by fixing one end of the cable and providing the other end with a counterweight, or by using counterweights of unequal magnitude and avoiding the fixity of the cables altogether, or by counterweights of the same magnitude, one of them being anchored.

A notable example of the use of counterweights is furnished by the Loschwitz Suspension Bridge across the Elbe, in Germany, a bridge having a total length of about 880 ft., that is, 480 ft. for the central span and 200 ft. for each side span. It is to be noted, however, that in this case the counterweights are intended for a purpose different from that proposed herein.

Counterweights in a bridge such as characterized do not change the statical nature of the trusses. They are known quantities, therefore the stresses in the cables and suspenders are known and constant quantities. The size of these weights may be controlled by proper arrangements of lever arms.

The advantages connected with such a construction may be summarized as follows:

1.—The cables take a part of the load from the trusses, so that the compression members are very considerably reduced in size;

2.—The counterweights are open to inspection, a matter of undoubted and great importance;

3.—The cables are free from temperature stresses;

4.—The safety of the bridge against collapse is increased; and

5.—The bridge can be erected in a manner similar to that of a suspension bridge.

The other part of the problem is of an esthetic character, and is important enough to deserve very careful examination, on account of the unusual size of the bridges. Observations have led the writer to believe that judgments in esthetic questions are very much at

variance, so that a discussion of the principal points of this subject seems to be timely, especially as the writer is not aware that these points have ever been brought very prominently before this Society.

In the nature of things, the design of a bridge must first fulfill all necessary technical and economical requirements before the esthetic side of the problem is taken up, and, consequently it is natural that the freedom of the bridge engineer in esthetic questions is more or less limited; therefore, whenever an opportunity presents itself, he should not let it pass, but, either alone, if he has the necessary qualifications, or in co-operation with an architect trained in bridge esthetics, he should endeavor to produce a work which will find general approval.

In this brief discussion the writer refers particularly to an arch bridge, but in the endeavor to make his meaning clearer, it is necessary to state some facts which are of a general character.

The esthetic effect of an arch bridge is enhanced if several conditions are realized, but the simultaneous existence of these is a rarity. These conditions consist in the symmetry of the structure; an odd number of spans and decrease in their length from the middle of the bridge toward the ends; if there is more than one span, the passing of the floor across the crown or crowns of the arches; and, moreover, for a highway bridge, a gentle rise of the floor from the ends toward the middle. Desirable as these conditions appear, they are nevertheless accidentals, and cannot be put forward as the cause of the satisfaction felt in viewing an esthetic structure; the finding of the true cause of this satisfaction, however, is the vital point of the discussion, carrying with it a hint to shape a design so that it will be esthetically effective.

Fitness cannot be regarded as causing the esthetic effect of a bridge, because a bridge may be perfectly fit for the purpose intended and be ugly at the same time; or, its effect may be esthetically satisfactory, while it may be entirely unfit for its purpose.

Decoration is another element to be considered in a bridge design, but is a mere addition, going beyond the utility of a structure. Forms of art, properly designed and wisely distributed, contribute to the appearance of a bridge, but they do not indicate the reason for real esthetic satisfaction. These embellishments can only be appreciated at close range, and are dwarfed into insignificance if a bridge is viewed from a distance; but the full effect of a structure can only be had from a proper distance.

It is quite natural to suppose that the arch line has something to do with the question, and it certainly has, but, considering it by itself—a mere curve—it can never be the cause of admiration.

Finally, it may be stated that neither taste nor style has any relation to this genuine satisfaction, at least, not in the case under consideration, as will be seen later. One must look in some other direction for the conditions of approval, and, in fact, these can only be found if an esthetic object is contemplated from a higher point of view, but an exposition of the relations between observer and object and a scientific explanation of the esthetic phenomena do not concern the engineer, as these are problems to be solved by metaphysics. Art is not an exclusive domain of the selected few—the intellectual leaders of the age—and only understood by them. It is an educational power—at least it should be—for a whole people, from which it follows that works of art must be understood by the masses to a considerable degree, if they are to be appreciated.

Taking this idea as a starting point, it may be asserted that the true arch is commonly understood, and, further, that it satisfies the esthetic feeling better than any other form of bridge; and now some substantial statements may be advanced in support of these assertions.

As to the first assertion, it is necessary to remind the reader of a simple fact. A load acting in the plane of an arched body—for instance, a segment of a ring which is supported at its ends—will spread these ends still farther apart. This is the way an arch acts, a simple phenomenon, stripped of all technicalities, understood anywhere and by everybody. The like cannot be said of every other form of bridge. There are, of course, some simple forms which are commonly understood, but they are lacking in certain elements, so that they will never surpass the arch in point of esthetics; it is not in their nature that they should. There are also bridge forms which require some effort for their identification. The designer, of course, knows exactly the way his mechanism will act, no matter how complicated, but the masses do not. However, they do know the arch at sight, are attracted by it, and understand its action.

The second assertion, containing the kernel of the discussion, requires the presentation of some facts which the writer believes will expose the true cause of esthetic satisfaction.

Esthetics is that science which sets forth the principles of art

deduced from Nature. Looking at the case in the light of this idea, it can be maintained that beauty in the works of the engineer, as in Nature, springs from the same source, and that in both cases (disregarding some elements of lesser importance) it consists principally in the manifestation of physical forces. The more clearly and perfectly the relations between these forces are expressed in the works of the engineer, or, in other words, the more closely his constructions approach an idealization of these relations, as between strength, load, and resistance, the more powerful will be the esthetic effect. An effective manifestation of the physical forces, however, is dependent on certain conditions which, if fulfilled, greatly enhance the esthetic effect. These conditions are mainly of an objective character, and they are: Intensity of expression, extension or size, uncommonness, and energy.

Take, for example, the force of gravity acting upon every substance. Its expression in stone and steel is more intense than in the lighter materials, and it is precisely for this reason that a stone or steel bridge is more pleasing than a wooden bridge.

Size plays a great rôle, and, in fact, it may be a source of the keenest pleasure. A bridge of any kind built on a very large scale gives a favorable impression, while the same bridge built on a small scale or represented by a model creates only indifference.

The first two conditions, of course, are complied with by any great bridge, but the case is different with the last conditions.

As to uncommonness, it is to be noted that phenomena of rare occurrence excite interest. A force like that of gravity acting along a vertical line is a common phenomenon, it is constantly before our eyes, so that it has ceased to interest us, certainly not in any marked degree, while, on the contrary, the appearance of inclined or horizontal forces strikes the mind as something new, and awakens interest. These latter forces are observed in those bridge forms which are governed by the arch principle.

The particular point, however, to which attention is called is the idea of energy, for in no form of bridge is this idea so irresistibly forced upon the mind as in the true arch, built either in steel or stone.

The beholder of an arch can see with his mind's eye the physical forces putting forth all their power to spread the ends of the arch still farther, flinging a thrust sideways against the supports to meet its counterpart. It is this fight for supremacy, between opposing forces,

the display of the tensest energy, the strength of the arch in action, the parry of a thrust and its safe guidance to the earth, which ever appeal to the imagination and reveal the beauty. Try as one will, one cannot ignore that thrust. It must have been this activity of the arch which gave rise to the significant and striking saying* of the old Hindus: "The arch never sleeps."

In a flat arch of long span the activity of the material is highly pronounced, and the struggle of forces is so strenuous that one actually speaks of the boldness of the construction.

If it is correct to see in the arch principle or in the way an arch acts the true cause of esthetic satisfaction, then this explains why bridges without this principle suffer a loss in esthetic effect, even to the point of its complete disappearance. Take as an illustration a truss with vertical reactions, but built like an arch. Here the arch principle has been severed from the arch line, the life has been taken out of the structure, it has been converted into a sham, and the esthetic effect is lost.

In viewing a great truss bridge with vertical reactions, the consciousness of the activity of the steel is not by any means as vivid as it is with an arch; it may be quite feeble, and it may even be extinct. One is impressed with the size and strength of the structure, but it is strength in repose—a giant asleep.

If the cantilever principle, as embodied in the common cantilever bridge, were exposed in its nudity to the mind of the observer, the carrying of the suspended span by the cantilever arms would produce in him a feeling of insecurity—of a possible disaster. The prevention of this feeling is accomplished by a trick played on his imagination by making the trusses appear to be continuous, and, at the same time, effectively confusing his understanding of their true action.

A suspension bridge, properly designed in every respect, is a handsome structure, although some features are to its disadvantage in an esthetic sense. A steel bent or tower, for instance, carrying the cables and anchored down at its base, contradicts the function of a column, because a column is intended to carry only vertical loads, and should not be subjected to the action of horizontal forces. Hinged ends and corresponding outlines of the tower or bent indicate, therefore, an

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* "History of Indian and Eastern Architecture," by James Fergusson.

improved appearance. The layman's idea of the action of a stiffening truss is anything but clear, and, owing to his limited knowledge of the great carrying capacity of a wire cable, it must appear to him as a rather slender member to carry the great loads which may be put on a long span. Further, these cables extend to a considerable length across a river on one side from the top of a tower, while toward the shore they are much shorter. Here the layman is confronted with a puzzle which possibly he can solve only after long and very careful cogitation. The unequal lengths of a cable with respect to the two sides of a tower make it difficult for him to balance the forces, and when, with his eye, he follows the cable toward the shore, he sees it suddenly vanish somewhere down into the earth, the opposing forces are completely hidden from his observation. Indeed, neither is the action of a suspension bridge as easily understood nor is the energy displayed in such a high degree as it is with the arch, where the struggle of forces is thrown into bold and naked relief.

The question which form of arch deserves preference in point of esthetics presents itself as natural, and, in order to reach a decision, it is only necessary to compare an arched rib with a spandrel arch. Even the untrained observer is satisfied with the arched rib as representing a physical symbol of the arch line existing in his imagination, especially if the rib has a constant depth, but he finds it difficult to obtain a realization of the arched line in the spandrel arch. The peculiar configuration of this truss deprives it in a considerable degree of its character as an arch, and this fact, coupled with the discovery of the smallest depth at the center of the span, where it is least expected, is the cause of confusion in his mind. The abrupt termination of the spandrel arch, that is, the perpendicularity of its high ends, obscures the expression of thrust, while the crescent arch, in which the two chords converge toward the springing line, is a form of truss best suited for the expression of a powerful and penetrating thrust which is parried by the quiet strength of the support.

It is seen, then, that, from the viewpoint of esthetics, the spandrel arch is unfit for large spans, and should only be used for small ones, while the arched rib must be considered as the correct form. Here the transfer of the loads to the rib by posts or suspenders, and also the power of the rib to carry these loads, is expressed clearly and unmistakably, in contradistinction to the spandrel arch.

The superiority of the crescent rib over other forms of trusses in certain cases should prompt an engineer to give it careful consideration. Properly designed, it is very efficient, safe, and economical; its free span length can be pushed far enough to satisfy any demand which is likely to be put forward, and, in point of esthetics, the arch bridge has no equal. The writer considers the ribbed arch as a source of the tensest energy, and, in fact, the only source of energy at the command of the bridge engineer.

The writer's investigations have led him to the conclusion that a skilfully designed arch bridge is superior in every respect to any cantilever or suspension bridge, and on this account he has offered these few suggestions. There are still other trussed arch bridges worthy of study which deliver the thrust against the shore masonry instead of against the river piers, and are essentially different from those considered herein, but, as the writer made no investigation of them (from lack of time), they are not presented for discussion.

An ideal solution of the problem requires exhaustive studies of a great number of designs. A body of engineers charged with such a work would have its hands full, but, if not hampered by financial considerations, the result would be a bridge which could hardly be surpassed.

An investigation with a view to determine the greatest feasible length of span of an arch rib has never been made. Such a length is largely dependent on the method of erection, which, in turn, may influence the character of the design.

DISCUSSION

MAX M. MILLER, ASSOC. M. AM. SOC. C. E. (by letter).—Esthetics in design is an essential branch of successful bridge engineering which, in the past, has been sadly neglected in the training and career of constructing and designing engineers. Until the last few years concerted action on the part of bridge owners, designers, and manufacturers to produce a pleasing structure was almost unknown. In the early days of bridge building the practice of awarding the contract for the construction of a bridge to the lowest bidder, whose design was prepared in competition with those of other bridge companies, was one of the most prolific sources of ugly structures; but, by degrees, a change for the better has been taking place. Mr. Miller.

In an increasing number of cases, the information furnished to bidders nowadays is sufficiently exact to eliminate some of the earlier sources of trouble. In practically all important structures and in more and more common structures, the type of design, including its esthetic treatment, is at least partly settled when the bidder is asked to compete. Thus the designing engineer and those associated with him assume an increasing responsibility as to the general appearance of a bridge.

In designing long-span bridges, the engineer is confronted with the problem of adapting a single and comparatively new material to an uncommon use. This in itself would present unusual difficulties in the way of satisfactory esthetic treatment; for it must be borne in mind that our conceptions of a pleasing structure are derived from past or existing works. In this respect, it is, in some degree, unfortunate that the most suitable material for the construction of bridges of great magnitude should not be better adapted to esthetic treatment; yet the superiority accorded to stone and masonry may be due less to intrinsic merit than to a longer familarity with their uses in construction.

Since bridges, including many ordinary crossings, are being built to an increasing extent as monumental structures, their esthetic design is becoming of correspondingly increasing importance. A pleasing effect in any structure can be attained in one of two ways, or, perhaps, by the proper combination of both:

First, by keeping constantly in mind the purpose for which the structure is being designed, and by proportioning its principal features so that the utilitarian and economical elements are blended, yet simultaneously discerned and appreciated by the observer. In such structures, architectural effect should be attained without recourse to embellishments or ornamentation of any kind, the effect arising solely from line and mass. Most masonry bridges, and also steel bridges of very long span, are included in this class. As such structures

Mr. Miller. form important features of the surrounding landscape, it is of the utmost importance that painstaking and exhaustive studies be given to them.

A second method of producing a satisfactory architectural effect, in a structure which otherwise would have a distasteful appearance, is by the addition of a certain amount of proper screening, but always in such a manner as not to hide the leading features of the design. The Alexander III Bridge, at Paris, is one of the most successful illustrations of this method of treatment.

The question as to where engineering ends and architecture begins in the case of a bridge is not an easy one to settle, and, consequently, it is undesirable to establish hard, fixed rules for the control of esthetic principles; nevertheless, we may lay down a few fundamental principles which are always found in a satisfactory esthetic structure, unless violated for good and obvious reasons. The author has mentioned some of the requirements, such as symmetry, odd number of spans decreasing in length from the center toward the ends, relative position of crown of arches and roadway, etc. He then says:

"Desirable as these conditions appear, they are nevertheless accidental, and cannot be put forward as the cause of the satisfaction felt in viewing an esthetic structure; the finding of the true cause of this satisfaction, however, is the vital point for discussion, carrying with it a hint to shape a design so that it will be esthetically effective."

Then he goes on seeking that cause, and concludes by saying:

"It is this fight for supremacy, between opposing forces, the display of the tensest energy, the strength of the arch in action, the parry of a thrust and its safe guidance to the earth, which ever appeal to the imagination and reveal the beauty."

This conclusion hardly accords with the majority of opinions heretofore expressed. To the writer these very conditions of symmetry, odd number of spans (up to the point where it becomes necessary to count them to determine whether they are odd or even), and position of roadway, are elements entering into a good-looking bridge. There are two other elements, however, which the writer would put at the head of the list: One of these the author casually mentions; the other he neglects entirely.

The first is fitness, not only in regard to strength and economy, but also surroundings. The author says: "fitness cannot be regarded as causing the esthetic effect of a bridge." It seems to the writer that the subject deserves more attention than Mr. Grimm has given it. Of course it is well known that there are very few structures which cannot be made strong enough, and, therefore, fit for use; they may even satisfy the requirements of economy and yet be inappropriate, for strength and economy may be combined in a structure and yet it may

be out of place on account of the surroundings. In such a case, fitness has everything to do with the question of the proper design to be adopted for a given crossing. In other words, the special purpose for which a structure is erected should be regarded as of such paramount importance in its design as to create in the mind a satisfactory impression of the suitability of that particular design for meeting the exigencies of the case. Mr. Miller.

As an illustration, consider the Niagara Gorge. On account of the enormous natural abutments available, the writer has yet to see a more satisfactory bridge design for this location than some form of the arch. Again, referring to the East River, on account of the comparatively level banks, and, consequently, the absence of suitable means for resisting the enormous thrust which an arch design would require, both fitness and economy seem to point to the suspension bridge as being the most appropriate design yet suggested.

The second element is simplicity, one of the most eminent qualities in a truly esthetic structure; for in every case the most beautiful and satisfactory results are obtained by the simplest arrangement of parts. A maze of members, some true, some false, and, occasionally, others redundant, such as may be seen in a long cantilever truss, creates anything but a favorable impression on the mind, because one is unable to distinguish at a glance the particular function of each member in the structure. In the suspension bridge or the arch, however, there are but five members: the roadway, the spandrel or suspenders, the arch ring or cable, the piers or towers, and the abutments or anchorages. It needs no special education or training to distinguish the peculiar function of each of these elements; even the most ignorant cannot but understand the necessity for each.

While these elements of fitness, simplicity, symmetry, number of spans, position of roadway, etc., are by no means all that may enter into a properly designed bridge, yet it is claimed that they have more to do with making a structure pleasing than merely the fight for supremacy between opposing forces. Furthermore, in his defence of the arch, the author mentions conditions which (the writer infers he would have us believe) place the esthetic value of the arch above that of other designs. For example, he says:

> "A force like that of gravity acting along a vertical line is a common phenomenon, it is constantly before our eyes, so that it has ceased to interest us, certainly not in any marked degree, while, on the contrary, the appearance of inclined or horizontal forces strikes the mind as something new, and awakens interest."

As far as this statement is concerned, what about cantilever bridges with horizontal or inclined lower chords carrying an enormous thrust? These fulfill the conditions as specified and illustrate further the principle of supremacy of forces, as enunciated by the author; but,

Mr. Miller. as a rule, a cantilever bridge is far from being as pleasing a structure as an arch or suspension bridge.

Before leaving the subject of arches, it may be well to point out one assumption made by the author in his designs on Plate XXXVIII, which rarely obtains in a span opening of the size of the one discussed, and which is an essential if not the controlling feature of economy in the adoption of his design of arches. Reference is made to the character of the approaches. In order that such a design should be suitable, gigantic natural abutments are necessary. These the author has supplied in his design, but he says nothing about them in his paper. As a rule, such bridges are required only in the lowlands of the country, across streams with wide-spreading, sloping, alluvial banks, furnishing no natural support for the well-nigh inconceivable thrust which such a design requires. It might not be difficult to select a suitable location for such a bridge; but the question would arise whether the traffic accommodated would warrant the expenditure required. Doubtless much that the author has left unsaid hinges on the question of approaches.

When properly designed, a suspension bridge can hardly be surpassed by any other type in point of esthetics; still, the author seems to feel that necessity for a small horizontal movement of the cables at the tops of the towers contradicts the function of a column so as to affect its esthetics. While this movement should by no means be neglected by the engineer, yet, as far as it affects the appearance of a bridge, it amounts to nothing. Under conditions of maximum angular variation, the deflection of the columns of a properly designed tower for a bridge not exceeding the maximum span yet constructed, is practically unnoticeable. The rocker-bent, suggested by the author as a substitute, is open to the more serious objection that its proper esthetic treatment would require a tower with a narrowing base, which is entirely at variance with esthetic design.

On the whole, then, although the steel arch may have before it a great theoretical field of usefulness as applied to long spans, the writer can hardly believe that it will find many applications to actual crossings, on account of the reason just cited; neither can he agree with the author's opinion "that a skilfully designed arch bridge is superior in every respect to any cantilever or suspension bridge."

Each type has its own field of usefulness, and although the field of one may overlap that of another for certain locations, we may hardly expect to see any one design fully supplanted by another.

Mr. Moisseiff. LEON S. MOISSEIFF, M. AM. SOC. C. E.—The author discusses the arch principle in the abstract and frequently succeeds in illuminating the subject from an uncommon point of view, which awakens many dormant suggestions in the reader and leads to further speculation and ideas. The paper deserves a full and extended discussion by

engineers interested in long-span bridges. Such a discussion would bring out many novel points of view, and should prove of mutual benefit. Mr. Moisseiff.

Mr. Grimm's predilection for the arch principle and, among arches, for the upright arch, appears rather early in his paper. Evidently it is based on the "estimates of weights for bridges of widely different designs, three arch bridges, a cantilever, and a suspension bridge," which estimates, the author states later, he has made. However, it appears that other types of bridges are dismissed in too summary a manner in favor of the upright arch. The inverted arch or suspension bridge certainly deserves more consideration and a deeper study of its merits.

It may be well to remember that a survey of actual achievements discloses the significant fact that the length of span of the longest arch has been doubled successfully by its rivals, the cantilever and suspension bridges. The arch type, therefore, has to overcome the strides made by these rivals, and to prove that it is more economical in construction, stiffer in use, and handsomer in appearance. This the author virtually undertakes to prove for the upright arch. In his opinion, the crescent arch is the most economical, most rigid, and the best looking type of bridge for long spans such as, for instance, a span of 1 800 ft. Throughout the paper he argues his case on three points, namely, economy, stiffness, and looks; but he fails to be convincing.

No data are given by the author which would enable the reader to compare, in some way, his designs of cantilever and suspension bridges and those of the arches denoted as Types *A, B,* and *C*. Bridges of the dimensions compared are not built too frequently, and their design is not yet standardized. Such structures require much study, and it may easily be possible that individual differences in their design may suffice to overcome the differences in tonnage computed by the author.

In the table of estimated weights the author gives that of the suspension bridge as 60 000 tons, that of the arch bridge *A* as 53 000 tons, and that of the arch bridge *B* as 45 000 tons. According to this estimate the suspension bridge weighs 7 000 tons more than arch bridge *A*, and arch bridge *A* weighs 8 000 tons more than arch bridge *B*.

The only difference between Bridges *A* and *B* is that the side trusses in Type *A* are curved with a versine of 40 ft., while those in Type *B* are horizontal. This difference in outline, which, at first glance, appears to be of no great importance, is, however, sufficient, according to the author's statement, to cause a difference of 8 000 tons, or 15%, in the weight of arch bridge *A*. How much variation in design would then be required to overcome the difference of less than

Mr. Moisseiff. 12% between the estimated weights of the suspension bridge and arch bridge *A*?

This is mentioned merely to illustrate the writer's statement that the author has not furnished sufficient data for a comparison of the different types discussed. The objection may be made that the author has endeavored to design the different types according to uniform rules and specifications, and that the comparison is fair; but it will be admitted that the design of a suspension bridge will differ very materially from that of an arch bridge in many important points, beginning with the choice of the versed sine to the length of the panels and ending with the proper allowable stresses in the component parts of the suspension bridge. Engineers will first have to be satisfied that the best or equally good designs of the different types have been shown for comparison, before they will be ready to accept any estimated weights, even if made by an able engineer.

This again can be illustrated by one of the author's assumptions. All the bridges compared are supposed to be of nickel-steel throughout. It is hardly good engineering at the present time to make the floor system of a bridge of nickel-steel except in case of extreme necessity. A bridge floor needs stiffness, and this can be supplied as well and at a less cost by structural steel. Nickel-steel is not stiffer than structural steel, the coefficients of elasticity being practically the same; nor are floor-beams and stringers designed to exact theoretical sections at any point. Constant sections and least thicknesses of plates and angles require much overrun. The greater strength of nickel-steel, therefore, could not be utilized to advantage in a floor system. True, the floor systems of all the bridges have been assumed to be of the same material, and, at first thought, the comparison is fair to all types; but second thought will disclose the fact that a suspension bridge, especially one with wire cables, will carry a uniformly distributed fixed load, such as the floor system, more economically than any other type considered. The writer believes that a floor system of structural steel, which, of course, would be heavier, would show the suspension bridge to be more advantageous.

"A suspension bridge would solve the problem, provided great care was taken in its design as a railroad bridge, but the writer does not consider it the best solution. Skilfully designed, the bridge proper shows economy and has a pleasing appearance, but it also has disadvantages. The tonnage is influenced considerably by the anchor chains and anchorages, and particularly by the towers and the general stiffness. Further, it is to be noted that the effects due to temperature changes and yielding of the anchorage masonry, and also the deflections, are considerably greater in suspension bridges than in arches. It is very difficult to inspect the anchorages, which is a serious drawback, as the safety of the bridge is dependent on them, and the anchorage masonry is a very costly item."

The writer does not agree with the above statement of the author. Skilful design and great care are required for any type of long-span bridge, and in discussions of various types it is always tacitly assumed that the design is at the height of the art, and that the best of care is given it, be it arch, cantilever, or suspension bridge. The effects due to temperature changes and yielding of anchorage masonry are not considerably greater in suspension bridges than in arches. There is no reason why they should differ for an arch of Type *A* or *B* and a suspension bridge of identical spans and versed sine. For a suspension bridge the elongation of the main span, due to an increase in temperature, the curve being of the same length, will be the same; that due to the side spans will be greater, as the length of the back-stay curve is greater than that of the horizontal chord of the side span in the arch type *B*. For the dimensions used by Mr. Grimm the writer has computed the difference to be about 6% of the side-span effect, or 2.5% of the total effect, of temperature changes. Against this the counteracting effect of the tower elongation for the same change in temperature is to be added, which will make the total effect due to temperature changes the same for both types. This also holds true for the effect of yielding of the anchorage masonry. Mr. Moisseiff.

The greater deflection of the suspension bridge is due only to the higher stress used for the cable wire; if, for instance, a nickel-steel chain of eye-bars is used, having the same unit stresses as the arch rib, practically the same deflection will result. This, of course, presupposes equivalent depth of stiffening trusses.

It is not difficult to inspect the anchorages of a suspension bridge if proper provision be made for it. If, as in present practice, the anchor chains are embedded in concrete, they cannot be inspected. This is done because the experience of a century has demonstrated it to be the best way of preserving them. There is, however, no difficulty in leaving the anchor chains open for inspection. It is true that anchorage masonry is costly, but so is abutment masonry for an extremely heavy arch thrust transmitted in a horizontal direction, which has to be resisted by the stability of a masonry abutment.

It is not true, as stated in the paper, that a suspension bridge is far more sensitive to a yielding of its supports than any arch bridge. With towers hinged at the foot and a shallow stiffening truss it will be, on the contrary, less sensitive. For equivalent proportions the same sensitiveness will result.

The author proceeds to demonstrate the inherent safety of the arch bridge by a paradoxical example. Suppose, he says, the side spans or the abutment masonry offer no resistance to the thrust of the arch, "even then the central ribs under their own weights would survive the injury, but by stressing the steel nearly to the elastic limit." The author finds the realization of this supposition improbable, but possible,

Mr. Moisseiff. "for example, by an earthquake." A suspension bridge would be destroyed "long before the pull in the anchor chains reached the zero value." This is true, but why is the failure of the river piers of the arch not just as possible "for example, by an earthquake"?

In reply to the above paradox may be brought the more rational argument that the stiffening truss of a suspension bridge may be crippled without endangering the bridge, while if a chord of the arch truss should fail, the arch in all probability would collapse.

The tentative proposal of an arch truss in connection with a wire cable as a permanent carrying member sounds well in the abstract. The question is however in order, why build a suspension bridge to carry the fixed load, or most of it, and an arch to carry the remaining load? Would it not be better to add sufficient steel to build a suspension bridge of the required stiffness, and omit the arch altogether, and be cheaper in the end? Where would the supposed economy of the arch assert itself in the combination of a cable and an arch?

As to the practical application of counterweights to the enormous weights represented by the pull exerted by the cable ends of suspension bridges of long spans, the difficulties are great and necessarily expensive.

Not knowing the forces computed by the author, the writer ventures to guess that the pull of the cables carrying their own weight and only one-half of the total fixed load on the arch, will be not less than 10 000 tons. To take care of this weight in the form of a counterweight will prove costly in materials and work.

As reference is made in the paper to the use of counterweights in the Loschwitz Bridge, in Germany, the writer wishes to quote from Professor Mehrtens' great work on the evolution of iron and steel bridges, published in 1908:

"The Loschwitz Highway Bridge has been opened in 1893 and is neither a cable nor a chain bridge. Its chords are riveted throughout and it has three hinges. The pull of the arch is taken up artificially by a bent lever system which is hidden in each end pier. In this and in other matters the bridge is an exceptional structure. Its peculiarities will, however, hardly cause imitation. After the experience of a century there is no need for an artificial provision for the arch thrust. This method belongs to the arrangements which have been denoted as not worthy of imitation."

The author's discussion of the esthetics of bridges is generally instructive and contains many good points, but his application of these principles to the arch bridge with extra deep crescent ribs, as illustrated in types *A, B,* and *C,* is not very successful.

The high esthetic valuation of the arch type has been transmitted to us by "esthetic habit" from the observation of masonry arches. These arches and their proportions have satisfied our senses, and we

have formed the habit of being pleased by their appearance. These proportions show, however, no such depth of arch at the crown as the one proposed by the author. A comparison of a considerable number of masonry arches will disclose the fact that the ratio of depth at the crown to versine of the intrados is far less than 110 : 250, as is the case in the author's design. In other words, there is far more depth of arch in the deep crescent arch than is compatible with a good esthetic impression. Mr. Moisseiff.

The long panels, which necessarily follow the great depth of the arch, result in lines too far apart and give an empty appearance. The observer will miss the simple, solid line of the arch rib to which his esthetic sense is accustomed; he will also miss the rhythm of recurring symmetric lines.

The growing depth of the arch toward the middle does not agree with the increase of the resultant thrust toward the abutments, and does not give that sense of safety and satisfaction which the author ascribes to it. As to the esthetic appearance of the crescent arch, opinions are divided. Some well-known authorities have compared it to the appearance of a man balancing on his toes. The combination of cables and a suspended arch will not improve the appearance of the structure.

In conclusion, the writer wishes to state that credit is due to those engineers who have introduced nickel-steel in bridge building, and have expanded the field of long-span bridges. The use of high-resistance steel will enable the bridge builder to overcome heretofore impossible difficulties, and will lead to many interesting discussions, Mr. Grimm's able paper being one of the first in this line.

Fr. Engesser,* Esq. (by letter).—The writer agrees fully with Mr. Grimm in all essential points, and particularly in his high estimation of the value of arched ribs, which require less steel than cantilevers and continuous trusses for long spans, as the abutments relieve the steel of a part of its work. Further, these ribs are subjected only to small secondary stresses, they take first place in esthetic respects, especially if the floor passes over the crown, as is the case with masonry bridges. On the other hand, they necessitate more massive abutments than bridges with simple trusses, and can only be applied advantageously if the soil is good. Compared with cantilever bridges, arch bridges are at a disadvantage in point of erection, but this can be removed by the application of a cable, as proposed by Mr. Grimm; however, in such a case, the rib would lose some of its characteristic beauty. Mr. Engesser.

Suspension bridges require a great tonnage of steel for anchorages and towers, and on that account the most favorable dip of the cables cannot be obtained as a rule, and for spans of 1 800 ft. financial

* Karlsruhe, Germany.

Mr. Engesser.

conditions are not as favorable as for arch bridges. On the other hand, the cables admit of higher stresses, on account of excellent material, are less influenced by wind, and, as they need no extra material for buckling, a longer span than for an arch is theoretically possible. By a proper mode of construction, it is possible to avoid too great a flexibility, which circumstance is of lesser importance with increasing length of span and dead load. While a suspension bridge with stiffening trusses of the usual depth would collapse under the hardly possible assumption of a complete yielding of its anchorage masonry, the sickle-shaped arch would resist destruction on account of its great depth, but the stiffening truss would stand if it were given the same depth as that of the sickle. The secondary stresses of suspension bridges with the common shallow stiffening trusses are smaller than those of deep sickle trusses, if one considers only such horizontal displacements of the masonry as occur under ordinary circumstances.

The appearance of properly designed suspension bridges is quite satisfactory; the play of forces is easily comprehensible, and, in the writer's opinion, the esthetic appearance of such bridges compares well with through arches. The great difficulty of inspecting the anchorages of suspension bridges must be considered as a particularly critical condition, and this difficulty, together with the financial question, are two of the principal reasons why suspension bridges find such a limited application in Germany.

Mr. Krohn.

R. KROHN,* ESQ. (by letter).—One can readily agree with Mr. Grimm's interesting expositions when he states that, for long spans, the arch rib is in many cases superior to all other forms of trusses with respect to economy and esthetic effect; but the writer does not believe that this superiority exists in all cases.

The required tonnage of steel is not alone the guide in judging the economy. It is true that the costs of a bridge are essentially dependent on the tonnage of the superstructure, so that this quantity forms an important part in the determination of economy, but the erection costs must also be considered, and these are not the same for all trusses and under all circumstances. The erection costs may be least for a suspension bridge; in another case they may be least for a cantilever or an arch bridge; and the differences may be so large that the extra costs for a greater tonnage are not only balanced, but possibly the bridge with a greater tonnage may prove to be less expensive. Just as important, or perhaps more so, are the costs of the piers and abutments, which Mr. Grimm does not consider. The difference in these costs may be so large that a comparison between different bridges with respect to economy is disturbed. Assuming a very poor soil, an arch of long span, and the hinges at a very high elevation, the safety of

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Mr. Krohn.

the abutments may cause their cost to be essentially higher than that of the superstructure. In aiming at a reduction of the total costs, under such circumstances, one would not use arch ribs, and, apart from that, the consideration of the safety of the structure would lead one to select a bridge with vertical reactions. The writer is in perfect agreement with the view that the arched rib is in many cases very advantageous, for example, when the rise of the arch is comparatively great, as in the Aar Bridge, in Bern, the Garabit Viaduct, across the Truyère, and others.

The writer also thoroughly endorses the author's statements in reference to the beauty of arched ribs. There is no doubt that the arched rib, in esthetic respects, is preferable to all other trusses, and its effect is grander and more powerful than that of suspension bridges; but one must not go so far as to designate all arch bridges beautiful, for Bridge *C*, according to the writer's taste, is hardly satisfactory.

All these objections, however, cannot detract from the importance of Mr. Grimm's expositions, which consist in pointing out the great excellencies of arch bridges from the viewpoint of economy and esthetics.

The writer is a convinced adherent of arched ribs, and has used them in his most important bridges, namely, the Rhine Bridges at Bonn and Düsseldorf, the bridge across the Baltic Sea Canal at Levensan, and the Aar Bridge in Bern.

It is to be hoped that this interesting subject, now up for discussion, will be instrumental in opening a greater field of application for arched ribs of long spans, in accordance with their excellent features.

Mr. Buck.

R. S. Buck, M. Am. Soc. C. E. (by letter).—This paper is very interesting in two essential particulars. First, in its radical departure from current ideas of practicable bridge design; and second, as an instance of that propensity, common among laymen, but fortunately rare among engineers, to inject into serious structural problems the very vague and chimerical element of beautiful form.

In the first particular the author is at least courageous, especially when the extreme tenuity of the data on which he presents his case is considered. In the second particular he is dragging into the pitiless limelight of practical consideration a vain dream of attained impossibilities.

The American bridge engineer may be somewhat slow to lay down certain things and pick up others; but, individually and collectively, and despite some mistakes, he has done good work, and has at least kept abreast of his European brother, perhaps passing a little ahead of him in some particulars. At any rate, an attempt to show American bridge practice to be unsound or unprogressive should be accompanied by more tangible data than are furnished by this paper.

Mr. Buck.

A bridge for heavy railroad traffic combined with highway traffic, spanning 1 800 ft., is a problem of such serious proportions, from the engineering, construction, commercial, and utilitarian standpoints, that it is fully entitled to immunity from the further complications of esthetics and unhealthy idealism.

When one endeavors to work into the bones and vitals of such an undertaking principles of pleasing form, conceived under happier and simpler conditions, one courts unreal fancies and multiplies real troubles. One cannot write into the structure the story of its conception and being so that "all who run may read," especially where there is a shortage of understanding of structural necessities and an excess of misapplied zeal for beauty.

It would be better to build the bridge on lines of safety, efficiency, and economy, and let its beauty lie in the direct, intelligent, and honest way in which it does its serious work. Let disciples of estheticism feed in fields less filled with real problems and difficulties.

The three examples of so-called esthetic long-span bridge design offered in this paper may present to some eyes possibilities of beauty; though, despite the author's rather elaborate explanation, it is not quite clear why; but they lack, in the presentation, necessary information as to what their abnormal forms and dimensions involve, in the way of stresses, deflections, sections, details, and costs, to establish any claim to real merit; and, at the same time, enough is shown to warrant the belief that they disregard fundamental principles of correct design, and are structually impracticable.

Mr. Grimm seems to appreciate as a general principle the value of small deflections, but apparently ignores it in considering his chosen designs.

In a parabolic, two-hinged arch rib of normal proportion of rise to span, the maximum moments, stresses, and deflections do not come at the center of the span, as in a simple truss, but near the quarter points, with the span about two-thirds loaded. Further, as the rib is made shallower, the bending moment, stresses, and deflections increase.

The crescent-shaped arch rib for a bridge is structurally incorrect, for the reason that the maximum rib depth occurs where it is not needed, and the rib depth is greatly reduced where the greater depth is needed. This not only increases bending moment stresses and deflections, but also temperature stresses, which are directly proportional to the center rib depth.

When it is considered that, with a uniform live load of indefinite length, the bending moments increase as the square of the span and the deflections as the fourth power of the span, the value of ample rib depth at the right point to resist them can be duly appreciated.

The author's justification for the crescent rib, with its maximum

depth at the center, appears as irrational as it is unique. Properly constructed arch abutments will not yield sufficiently to cause considerably increased stresses in the arch rib, and it is wholly improper, from a structural point of view, to sacrifice real rigidity, efficiency, and economy to the remote possibility of the failure of the abutments. If they should fail, the possibility is still more remote that they will fail in such a manner and only so far as to permit the salvation of the structure by the rib acting as a simple truss. Therefore, by increasing the center depth beyond what is required by rigidity and economy, and decreasing the depth at the haunches beyond this point, the author purchases, at the price of large increase in weight of metal and greatly increased deflections, a doubtful insurance against a phantom possibility of abutment failure. Mr. Buck.

Doubtless, the author, if he ever reaches the point of detailing his chosen design, will gladly barter this insurance against abutment failure and his idea of pleasing form for even a small reduction in some of the rib sections wherein serious troubles lurk.

Assuming this design practicable, from other points of view, in a bridge of such span and for such service as this, it would probably be necessary, in order to bring deflections and stresses within practicable limits, not only to increase the rib depth at the haunches, but to make it greater there than at the center.

Aside from the purely mathematical aspects of the case, it might be fairly claimed that, even to an esthetic eye, if affected by a small understanding of structural needs, these crescent ribs look unpleasantly thin at the haunches and near the springing. Further, when the space below the arch is so filled with construction, the arch effect is largely lost.

The author's casual dismissal of the spandrel-braced arch as unworthy of consideration, is, to say the least, a trifle unjust. Where length of span or conditions of erection preclude the use of a simple span, the spandrel-braced arch can compete in cost with any other type of bridge for heavy railroad traffic, has a much higher degree of rigidity, and should satisfy any reasonable demands as to appearance.

From the standpoint of theoretical design, it is more logical than the parabolic arch, either crescent-shaped or with parallel chords. It conforms more closely to the demands of the bending moments for which truss depth is required, and its failure to conform still more closely is fully justified by the demands of simplicity and needs of erection.

When the Niagara Railway Arch (spandrel-braced) was subjected to its test load—about two-thirds of its estimated capacity—the maximum deflection was only 1 in. Probably no other railroad bridge of equal span has shown a greater degree of rigidity and a smaller deflection.

Mr. Buck. A steel arch, according to the teaching of textbooks, is in certain essential features a suspension bridge turned upside down, but with one very important difference. In a suspension bridge the cables and suspended superstructure are in a state of stable equilibrium, and any tendency to produce vibration is resisted by the force of gravity, which tends to bring them to a state of rest. This feature is one of the most valuable assets of the suspension bridge design, and goes far toward counteracting the undesirable features of large deflections.

A steel arch is in a state of unstable equilibrium, aggravated by gravity and counteracted only by the web system of the arched trusses and the lateral bracing. The force of any influence tending to set up vibration in a structure in unstable equilibrium is increased by gravity, and in such structures the effect of isochronous impact, with its incalculable force, must be carefully guarded against. This is a force demanding consideration in bridges of normal form and proportions, and in which stresses and strains are far within statically safe limits. When abnormal forms and proportions are indulged in, and these are coupled with abnormal stresses and strains, the danger point is approached with great celerity.

In the writer's opinion, the forms and proportions of designs *A* and *B*, especially when coupled with the high stresses and strains in the nickel-steel the author proposes to use, will render deflections excessive and be unable to keep vibrations from the danger point.

While the enormous weight and inertia of such a structure would doubtless keep it from often responding seriously to isochronous impact, it would in time do so; and, with such form and dimensions, the weight itself would be a source of danger, by reason of the momentum of such a mass and the great distance, vertically as well as horizontally, of the point of maximum movement from the points of support.

If treated as a truss resisting lateral moments, the main spans of the author's designs cannot properly be considered as only 1 800 ft. long and fixed at the ends, but, on account of the rollers under the ends of the main span, the end spans have a marked influence on its stresses, deflections, and vibration. A further material influence is the curvature and consequent lengthening of the chords of the arch.

As a specific, if limited, indication of what might occur in the way of vibration in a structure of such unprecedented proportions as the author's designs, the Niagara Falls and Clifton Arch Bridge may properly be cited.

This bridge is perhaps the closest existing approach to the author's designs. It is a parabolic, two-hinged, braced arch, and, the writer believes, is the longest arch span in the world. It is 840 ft. long, with a rise of 150 ft. from the springing line to the center of the rib at the middle of the span. The center rib depth is 26 ft., measured vertically, and this depth is maintained normally to the rib axis to the quarter

points, from which points the chords are parallel almost to the abutments. The trusses are battered, being about 69 ft. apart at the springing and 30¼ ft. apart from center to center of top chords at the middle of the span. The width of roadway is 47 ft. from center to center of fascia girders, these forming with the lateral bracing in the plane of the floor a wind truss 47 ft. deep. Mr. Buck.

This lateral system in the plane of the floor is designed to carry one-third of the floor wind load to the end bents and down these to the abutments, the other two-thirds being carried directly down the bents, and thence through the arch lateral system, to the abutments.

The arch was designed to carry an equivalent, in trolley cars and uniform load, of about 2 700 lb. per lin. ft. The unit stresses, the writer believes, are somewhat smaller than is usually allowed in highway bridges for similar service.

At times, under heavy but not statically excessive loads, this bridge has been subjected to such vibrations as to make it advisable, in the interest of safety, to restrict the movement of the traffic in a way not demanded by static conditions.

These excessive vibrations have not been frequent, and usually the bridge is very steady, considering its form, length of span, and lightness. Further, such vibrations have caused no damage to the bridge, nor impaired the adjustment of any of the large number of adjustable members. Twice the bridge has been subjected to severe stress and some damage by the ice gorging in the river and crowding against the steelwork at both ends. The damaged members were replaced or repaired, without any permanent impairment of the strength or efficiency of the bridge.

The lesson taught in this case is that, in long-span, parabolic arches, deflections and vibrations are likely to be serious, even when statically well within safe limits of loading. The combined influence of all the factors affecting deflections and vibrations should not be allowed to approach any closer to the limit of safety than in the case of the Niagara Falls and Clifton Bridge; but, with such excessive spans and loads as the author treats, should be brought farther from it.

In designs *A* and *B*, eliminating for the time being the incalculable uncertainties and difficulties of excessive span and extraordinary form and details, there are but two features which tend to greater rigidity than in the Niagara Falls and Clifton Bridge. These are greater center rib depth and the larger ratio of dead to live load. The first is more than four times that of the Niagara Falls and Clifton Bridge, and the second is 2.3 as compared with 1.6 for that bridge. However, the relative advantage of the first is greatly impaired by the crescent shape and the reduced rib depth at the haunches and near the springing; and that of the second by the more severe character of the heavy railroad load.

Mr. Buck. In all other features the characteristics of the author's designs are more conducive to deflection and vibration. Here the ratio of span to width at piers is 21.2 as compared with 12.2 of the Niagara Falls and Clifton Bridge. The ratio of extreme center height above piers to width at piers is 4.2 in the former as compared with 2.4 in the latter. In the former, unit stresses, and consequently strains, would be about twice what they are in the latter, on account of the use of nickel-steel, the modulus of elasticity of which is not materially different from that of ordinary carbon steel. Add to these conditions the much severer impacts of railroad traffic, the roller end bearings of the main span, and the fact that the span considered by Mr. Grimm is so much greater than anything yet tried or even seriously considered for this type of bridge, and also, judging from actual experience, it is not unreasonable to assume that the author is on doubtful if not dangerous ground, at least unless and until he can modify and detail his designs so as to demonstrate more clearly that they are within reach of safe possibilities.

While the writer has not at hand the definite detailed data to demonstrate the inaccuracy of the comparative weights of the different types of bridges given in the paper on page 238, he is compelled, by his general knowledge of relative weights of types, to question their accuracy until the basis of the estimates is indicated more definitely.

The weights of 1 800-ft. cantilever and suspension bridges can be closely approximated from the design of these types worked up in more or less detail for the new Quebec Bridge. However, the absence of more detailed information as to designs *A, B,* and *C,* and the further fact that it would require a large expenditure of time, labor, and money to calculate and detail such very unusual designs so as to make even a fairly approximate estimate of weight, it is not unreasonable to assume that Mr. Grimm has calculated the weights of these designs from very general calculations of stresses and very limited details. Such estimates, especially in the case of such abnormal forms and proportions, without any precedent to guide, and with a natural tendency to demonstrate the soundness of a preconceived preference, are invariably low.

It is hardly unreasonable to ask a much more detailed design and estimate than that given by the author, before according belief in the claim that the weight of steel can be reduced from 70 000 to 45 000 tons by passing from a normal cantilever design like that of the new Quebec Bridge to the abnormal designs, *B* and *C.*

Has the author, in his estimates of weights, taken into account the very considerable quantity of steel that would be required to anchor back the two half spans during erection? The suspenders supporting the floor (presumably eye-bars) would hardly be adequate for the purpose.

An important feature in determining the practicability of these designs is the hinged roller bearings at the ends of the main spans in designs *A* and *B* and on the pivot piers of design *C*. Roller bearings become a serious problem long before the weights they carry assume such proportions as these, and the writer believes that it would be impossible to create a roller bearing which would not preclude the adoption of even an otherwise meritorious design. Mr. Buck.

Aside from the difficulties and cost of manufacturing such large roller bearings, they are very undesirable features in the structure, not only because they would, as previously indicated, increase the deflections and vibrations, but would also increase very materially temperature stresses in the main span.

Comparing designs *A* and *B*, and accepting the author's comparative figures as correct, it would seem that $840 000 (7 000 tons of steel, at, say, $120 per ton) is a very heavy price to pay for the concession to the esthetic eye of having the bottom chords of the end spans curved, aside from the aggravation of instability caused by having three crescent arches connected in tandem, so as to transmit temperature and live-load strains from one to the other.

In design *C* there is some mitigation of the serious results of the excessive arch spans of designs *A* and *B*, but it leads to the loss of the fundamental reason for embarking upon such types—esthetic effect. It incorporates the objectionable features which Mr. Grimm attributes to the cantilever type and adds an offensive transition in the midst of the main span from one type of construction to another, in which it would be impossible for any eye, other than that of its parent, to find any beauty or other justification.

In this latter design it is even more difficult to concede the possibility of saving 25 000 tons of steel by merely using for the suspended span a type of arch uneconomical for heavy railroad traffic, in place of a simple truss.

It is unfortunate for the definite determination of the accuracy of the author's assertions, that he did not furnish more information as to the basis of his deductions. In short, to acquire title to credit he must prove his case.

The writer has not undertaken to wade through the mass of computations and details of construction necessary to determine by mathematical proof the inaccuracy of Mr. Grimm's assertions. He merely draws on his knowledge of current practice and his own practical experience in actual design and construction of a considerable variety of types, some necessarily rather extraordinary. He knows from such experience that in statically indeterminate structures, especially an aggravated case like a crescent-shaped, two-hinged arch, general deductions, without laborious computations, are worthless and misleading.

Mr.
Buck.

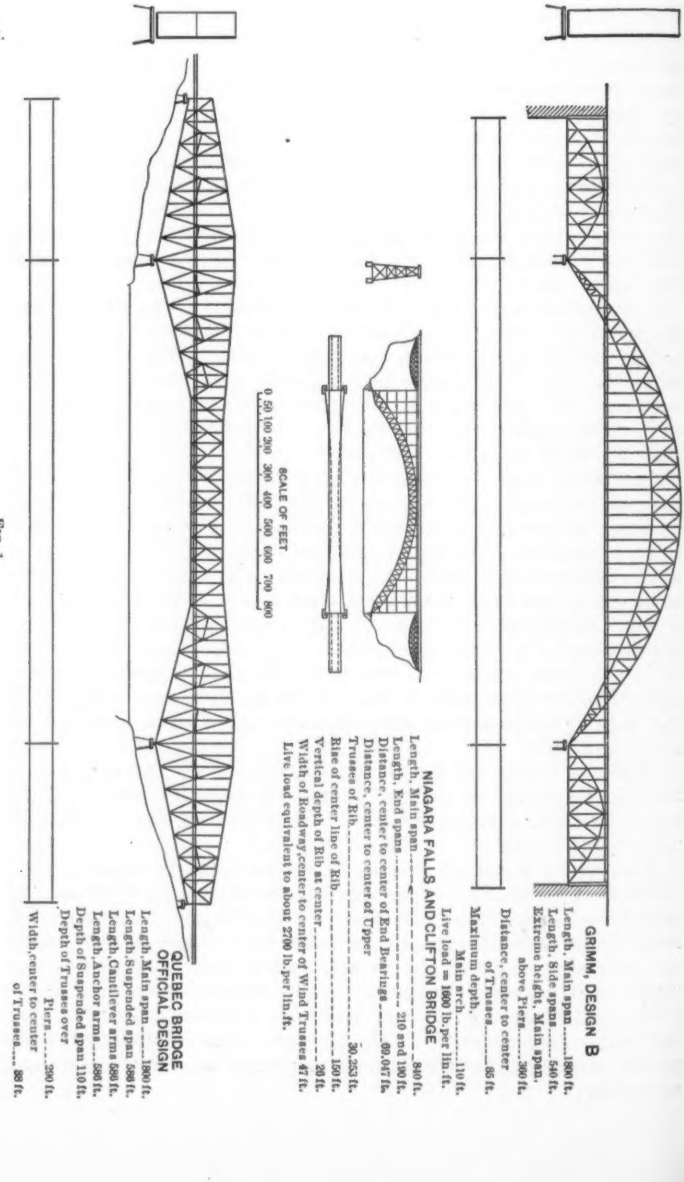
GRIMM, DESIGN B
Length, Main span.........1800 ft.
Length, Side spans.........540 ft.
Extreme height, Main span,
above Piers.........360 ft.
Distance, center to center
of Trusses.........85 ft.
Maximum depth,
Main arch.........110 ft.
Live load = 1600 lb. per lin. ft.
NIAGARA FALLS AND CLIFTON BRIDGE
Length, Main span.........840 ft.
Length, End spans.........210 and 190 ft.
Distance, center to center of End Bearings.........69.047 ft.
Distance, center to center of Upper
Trusses of Rib.........30.253 ft.
Rise of center line of Rib.........150 ft.
Vertical depth of Rib at center.........26 ft.
Width of Roadway, center to center of Wind Trusses 47 ft.
Live load equivalent to about 2700 lb. per lin. ft.
SCALE OF FEET
0 50 100 200 300 400 500 600 700 800
QUEBEC BRIDGE
OFFICIAL DESIGN
Length, Main span.........1800 ft.
Length, Suspended span 586 ft.
Length, Cantilever arms 586 ft.
Length, Anchor arms.........586 ft.
Depth of Suspended span 110 ft.
Depth of Trusses over
Piers.........290 ft.
Width, center to center
of Trusses.........88 ft.

FIG. 1.

In order to furnish a general basis of comparison, the writer gives in Fig. 1, and drawn to the same scale, outlines of design *B*, the Niagara Falls and Clifton Arch Bridge, and the official design of the new Quebec Bridge. From this one can perhaps in a measure appreciate what a stride it would be to go from the second to the first, and also the striking contrast between the direct, practical, intelligent outline of the third and the hopelessly strained and unjustifiable outline of the first. Mr. Buck.

The last, with all its straight-line severity, should have far more beauty to the understanding eye than the first, with its painful striving after an impossible effect and its incongruous invasion of the sub-arch space with line-obliterating construction.

Mr. Grimm's objections to existing and seriously proposed types of bridges are largely academic. The remedy he proposes for eliminating these objections would not only be a case of flying from known to unknown evils, but would in many respects be a case of flying into the arms of demonstrably greater evils.

Ernst Jonson, Assoc. M. Am. Soc. C. E. (by letter).—It is indeed highly desirable that every engineering structure be designed so that, besides fulfilling its physical purpose, it will, in some measure, give the beholder the same pleasurable feeling which he experiences before the best works of architectural art. Mr. Jonson.

It is a mistake, however, to suppose that this result may be attained by following certain rules. To the architectural designer, rules are not only worthless, but an actual hindrance. Conscious reasoning seems to interfere with that subconscious mental process which the creative function of the artist implies. Rules or principles of art cannot be used safely, even by the critic in forming his judgment, but only when accounting for it after it has been formed.

Engineering works can become works of art only in so far as the engineer becomes an artist. The most expedient means to this end, whether it be the general cultivation of the Engineering Profession, or intimate and harmonious co-operation of engineer and architect, can be found only on trial. To the writer, the former seems the most promising. Co-operation too often results in a superimposed architectural treatment having no intimate connection with the structure, being sometimes even detrimental to its artistic value.

The fine arts are not sciences, and cannot be formulated in rules. Attempts have been made to prolong the life of schools of art by formulating their laws, but this expedient has resulted, not in preventing its death, but in a sort of mummified after-existence.

The only way to art lies in artistic culture, or the assimilation of the unformulated essence of art into the organization of the mind. This result is attained by observation of the best among existing works and attempts to create new ones.

Mr. Jonson.

The question as to what is best in art is no more capable of scientific solution than the problem of artistic creation. The only true criterion of art value lies in the persisting opinion of the cultivated, backed up by equally enduring popular approval. No rationalistic short-cuts are possible. Poor works of art sometimes win the approval of the masses and even that of the cultivated, but this is for a few years only. When the enticement of fashion vanishes, the poor work sinks into obscurity. The true work of art alone has an enduring place in the esteem of mankind.

These assertions are proved by actual experience. The most rationalistic esthetician is not generally the best artist; nor has the recognition of the world's great works of art been established or maintained by arguments. The money value of a work of art, therefore, is a function of the dictum of taste, as well as of the degree to which this dictum has been confirmed by the test of time. No amount of reasoning would ever make a \$50 painting worth \$50 000.

Many interesting generalizations may be made from the characteristics observed in good works of art, but, being empirically derived, they have no universal validity, and must accordingly be applied under the guidance of taste. It would probably be difficult to find a work of art which does not violate one or more of the so-called principles of art.

Let us now examine the architectural rules, the observance of which the author holds to be essential to good bridge building.

Symmetry is as common a characteristic of bad architecture as of good, and is by no means a universal characteristic of the latter. It is doubtful if the application of symmetry to the Erechtheum on the Acropolis at Athens, or to the Cathedral at Amiens, would have improved these masterpieces of architectural art.

An odd number of openings is a common characteristic of good architecture. Yet there are many notable exceptions to this rule, especially when there is evident occasion for departing from it, and sometimes even in works of the highest merit when there is no such occasion.

Decrease in length of spans from the middle toward the ends is not a predominating characteristic of good architecture in general, or even of good bridge design. The rule is, rather, uniform length of spans, except where topography or traffic demands one or more central spans of greater length than the end spans. One of the most artistic forms is the masonry arch bridge with spans of uniform length.

The passing of the floor over the crowns of the arches is unquestionably a characteristic of the best arch bridges. When this is not practicable the arch bridge is artistically impossible, the suspension bridge or even the truss bridge being preferable.

A gentle rise in the floor of the bridge is not a common characteristic, except where the shores are low and traffic or stream flow demands a rise. Mr. Jonson.

The author's arguments in favor of the superior artistic value of the arch bridge are worthless simply because art values cannot be demonstrated by reasoning. In the past, most bridges were arch bridges; hence this type has reached the highest artistic development, and has accordingly been most highly appreciated, but this does not prove that in the future the suspension bridge and the truss bridge may not reach the same artistic level.

The arch for long spans is artistically desirable only when the shores are high, so that the roadway clears the crown, for the arch line must never be intersected by it, just as the cable line must never be intersected in suspension bridges.

According to the author's reasoning, the flatter the arch the more beautiful it ought to be. This is not true. As a matter of fact, the most beautiful arches are those which approach the semicircle.

The author's exposition of the nature of art as a mere revelation of mechanical principles fails to satisfy any one of developed artistic taste. Such expressions of the laws of mechanics, and even those of pure mathematics, are undoubtedly elements in art, but only to a limited extent. The vital element in art, that element through which the character of a people is reflected in its artistic creations, is quite beyond mechanistic explanations, and, as far as the writer knows, has never been explained satisfactorily.

There is an artistic element in every structure. The difference between good and bad architecture is not one of kind, but of degree. All construction is architecture, and all architecture is construction. Architecture is not a thing apart from construction, but an element in it. This artistic element is the resultant of two distinct though co-operating components, namely, expression and beauty.

Expression is that quality in a work of art through which it affects our feelings. All material pleasures and phenomena have certain emotional associations, represent certain moods. It is through this association that art produces the effect in us which we call expression. The expression in a work of art, therefore, is something which cannot be discovered through reasoning, but can only be felt; nor can it be infused into the work by reasoning, but only by feeling.

Beauty is that quality in a thing which we perceive through our æsthetic sense, which is not an emotional function but an instinctive intellectual one. Beauty is a kind of harmony with the nature of our intellect, not an abstract and remote one like logical and mathematical truth, but a concrete and often symbolical one. Therefore, it cannot be constructed by reasoning, or according to rules, but, since it is in its essence truth, it must conform to all the laws of the human

Mr. Jonson. intellect. In other words, beauty, though not produced by rule, is governed by certain laws. A structure, therefore, must be rationally and honestly built in order to be beautiful. The absence of beauty in it may be discovered by reasoning, but its presence can only be felt.

Every honestly and intelligently designed structure possesses what may be called a normal amount of beauty, which may be heightened by the co-operation of true artistic taste, acting always within the limits of honesty and reason, or which may be obscured by false architectural treatment, even to the point of not being discoverable except under certain favorable conditions, such as distance or darkness, which obliterate the disfigurements and bring out the normal beauty of the structure.

All dissembling, therefore, whether in materials or construction, is prohibited in architecture. No material may be treated so that it represents another material. As long as the builder works in stone or wrought metal the temptation to imitate another material seldom arises. It is mainly when the more easily moulded materials, such as concrete, wood, cast and sheet metal are used that the designer is overcome by a desire to imitate the more laboriously wrought ones, or to utilize the architectural forms evolved for them. To disguise one kind of construction as another is equally bad architecture.

Mr. Lindenthal. Gustav Lindenthal, M. Am. Soc. C. E. (by letter).—In connection with this paper, it is interesting to compare a design for a five-hinged arch, suggested by Mr. Charles Bender,* a sketch of which is shown in Fig. 2.

FIVE-HINGED ARCH

From Charles B. Bender's "Principles of Economy in the Design of Metallic Bridges," published in 1885.

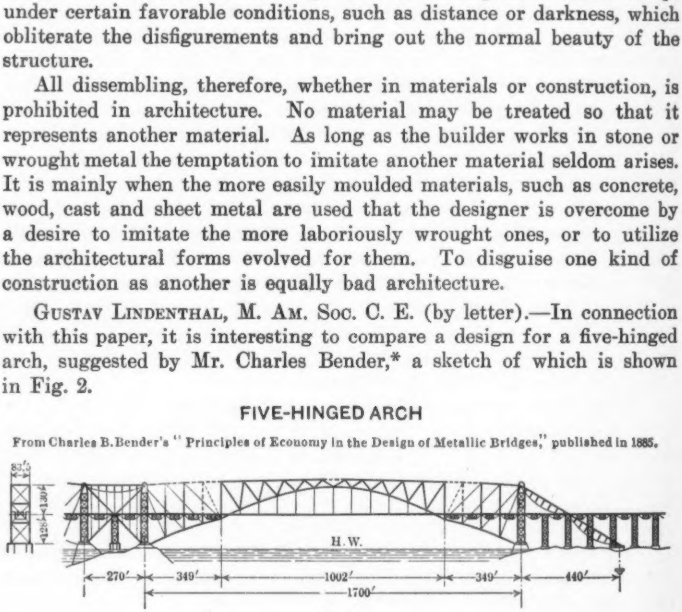

Fig. 2.

A full description and strain sheet are contained in his book, from which merely the following general data are taken: Live load for floor and viaduct, 3 000 lb. per lin. ft. of track, with 9 000 lb. per sq. in. in tension; live load for trusses, 2 000 lb. per lin. ft. of track, with 15 000 lb. in tension from loads and wind.

The unit stresses and loads assumed by Mr. Bender were the same as those in the Firth of Forth Bridge, designed by the laste Sir Benjamin Baker, Hon. M. Am. Soc. C. E., with which, in fact, he compares his design to prove its economy.

* "Principles of Economy in the Design of Metallic Bridges," 1885.

From the 5 330 ft. of bridging between the end towers of the Forth Bridge, Mr. Bender found the weight of his five-hinged arches to be 24 360 tons. The Forth Bridge at that time was estimated at 42 000 tons. The actual weight of structural steel, when the bridge was completed, was more than 45 000 tons, principally because of the higher wind pressures which the English Board of Trade compelled Sir Benjamin Baker to use. Mr. Lindenthal.

Of course, Mr. Grimm is well aware that no one would use nickel-steel exclusively. It is evident that his round figures, based on nickel-steel, are meant merely for convenience of comparison, and for that purpose, they are justified.

Now, taking Mr. Bender's five-hinged arch, and adapting it to nickel-steel, with the unit stress of 30 000 lb., and to the greater length of span in Mr. Grimm's proposition, there will be obtained as a safe round tonnage, in a length of 2 880 ft., 30 000 tons of nickel-steel required to carry the load on two tracks of 16 000 lb. per lin. ft., plus wind, etc. Mr. Grimm's lowest estimate of 45 000 tons of nickel-steel, therefore, would still be 15 000 tons, or 50%, higher than for a design on the lines of Bender's five-hinged arch. In the search for something light—if that be the important end in long-span bridges—Mr. Grimm appears to have been successfully anticipated by Mr. Bender by 25 years.

It is also a question whether Mr. Bender's five-hinged arch would not appear to be less inept as a basis for a homily on bridge architecture than Mr. Grimm's arched trusses.

Paul Chapman, Assoc. M. Am. Soc. C. E. (by letter).—Mr. Grimm has presented several novel designs for long-span arches, which should not pass without comment. Several features of the designs may be criticized from an esthetic standpoint. In an arch, one naturally expects massive abutments at the ends of the main span. The lack of these in the author's designs, produces a sense of insecurity and consequent dissatisfaction. The broken contour lines of the top and bottom of the structures do not present a pleasing appearance. The only sharp breaks in contour should be over a support or an anchorage. The tops of the crescent arch ribs project several hundred feet above the roadway (which is the top of the remainder of the bridge), and being only about 75 ft. on centers in width, must produce a feeling of instability. This would not be so pronounced if the roadway were near the tops of the main arch ribs. The arch* designed by Charles Worthington, M. Am. Soc. C. E., has the same main span (1 800 ft.) as the crescent designs, and is much more pleasing to the eye. The main span is very similar to the Washington Arch over the Harlem River, except in size. A little architectural embellishment to Mr. Worthington's design would produce a truly beautiful structure. Mr. Chapman.

* *Engineering News*, Vol. 63, p. 577 (May 19, 1910).

Mr. Chapman.

While what may seem pleasing and graceful to one, may seem the reverse to another, the writer thinks he is not alone in saying that none of the three crescent-shaped arches is as pleasant or graceful in appearance as any suspension or cantilever bridge of large span yet built.

The three designs may be criticized on account of their difficult erection. The erection of a structure having members 360 ft. above the springing line and 900 ft. from the shore, would undoubtedly be a difficult and expensive undertaking—enough, almost, in itself, to bar the designs. The arch designed by Mr. Worthington, having a rise of only 164 ft. is much simpler for erection. Generally, the erection of all large arch bridges is difficult, in comparison with cantilever or suspension types of bridges.

The arch designs presented may be criticized on account of lack of stability under lateral pressure. The necessity of carrying the wind stress in a system independent of the arch ribs, may be shown by a few rough calculations. Fig. 3 is a rough outline of Mr. Grimm's

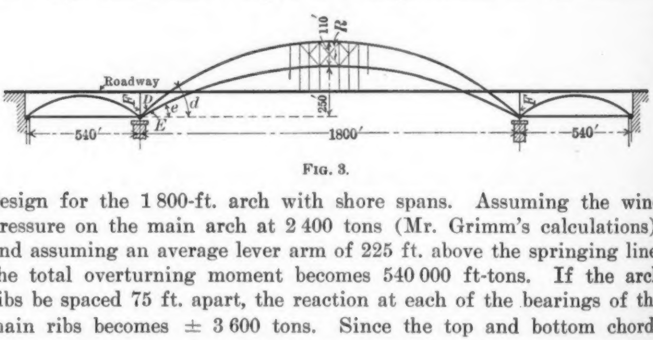

FIG. 3.

design for the 1 800-ft. arch with shore spans. Assuming the wind pressure on the main arch at 2 400 tons (Mr. Grimm's calculations), and assuming an average lever arm of 225 ft. above the springing line, the total overturning moment becomes 540 000 ft-tons. If the arch ribs be spaced 75 ft. apart, the reaction at each of the bearings of the main ribs becomes ± 3 600 tons. Since the top and bottom chords of the arch ribs are parabolic, the stress in them, due to this reaction, becomes for D $\left(\pm\ 3\,600 \times \frac{\sec.\ d}{\tan.\ d - \tan.\ e}\right) = \pm\ 18\,800$ tons; and for E $\left(\pm\ 3\,600 \times \frac{\sec.\ e}{\tan.\ d - \tan.\ e}\right) = \pm\ 16\,900$ tons. It is evident that an additional sectional area of more than 1 100 sq. in. would be required in each of the chords, D and E, due to this overturning alone, and very large elastic distortion, and possible failure of the structure, might result. The designer should remember that, with a compression chord 2 000 ft. long and only 75 ft. wide, the elastic shortening of the windward truss and lengthening of the leeward truss would produce a relatively large lateral deflection. It is evident from the above, that an entirely independent system of wind bracing is necessary. This might be accomplished by heavy horizontal bracing in the plane of the

floor and heavy vertical bracing in the plane of the bent marked *F;* but, in any case, at a great outlay in material. Mr. Chapman.

The designs submitted might be criticized on account of deflection, and vertical vibration. The author states that the arches are but slightly influenced by temperature changes, then it naturally follows, in the arch, that the deflections under full or partial loads would be large, since the temperature stresses vary inversely as the flexibility of the structure. The hangers supporting the floor at mid-span are approximately 125 ft. long, and would cause vibration from a moving live load. The writer believes that there would be considerable vibration in the main arch; but he does not desire to express a decided opinion without considering actual areas of sections, details, etc.

The writer has given considerable study to the cause of vibrations, and, aside from a general theoretical law, has come to the conclusion that indeterminate structures generally are less subject to vibration than simple structures. The general principle of this may be illustrated by reference to Fig. 4 which represents two beams, *G* and *H* (of equal depth but unequal length) fixed at their opposite ends, but joined together by a pin. Let them be deflected by a force, as shown

FIG. 4.

by the dotted lines, and suddenly released. It is evident that the short beam will tend to return to its normal position more quickly than the long beam, and will be retarded by it. This naturally reduces the vibration of both beams. In the arches in question, Fig. 3, the office of the short beam is performed by the horizontal thrust acting between abutments; the office of the long beam by the crescent arch acting as a simple beam. Warren girders are usually free from excessive vibration, because the office of the long beam is performed by the riveted connections. Cantilever bridges, especially those having suspended spans, are generally considered as vibratory. The writer has devised a method of reducing the vibrations in the latter class of cantilever bridges, without producing an indeterminate structure under full loads, which he may illustrate at a later date.

The designs submitted should be criticized on account of excessive cost as compared to cantilever or suspension bridges. The writer believes that the "arch principle" does not compare favorably with either the "suspension" or "cantilever principle." Basing calculations on data at hand, it is believed that the estimate for the cantilever bridge should be a trifle more than 35 000 tons (nickel-steel) instead of 70 000 tons. The estimate of 35 000 tons was obtained by assuming the anchor spans to be built of structural steel, and then reducing to an amount

Mr. Chapman.

of nickel-steel equal in cost to the structural steel, which produces considerable economy. The writer believes the estimate of 60 000 tons for the "suspension bridge" to be too high, because he finds the results obtained by the "Work Method" and the "More Accurate Theory" much in excess of the true stresses. He is of the opinion that the "cantilever principle" is the most economical and practical for use where conditions are similar to the case cited by Mr. Grimm, who regards it as "crude" and "uneconomical." Its economy for uniform load may be shown by reference to Fig. 5, which represents a series of simple spans; Fig. 6 represents a series of cantilever spans discontinuous at the center of alternate spans; and Fig. 7 represents a series of cantilever spans discontinuous at the quarter points of alternate

FIG. 5.

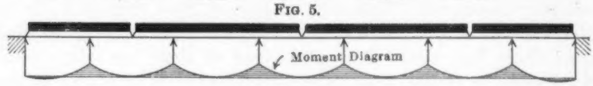

FIG. 6.

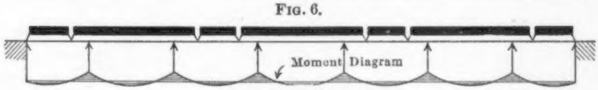

FIG. 7.

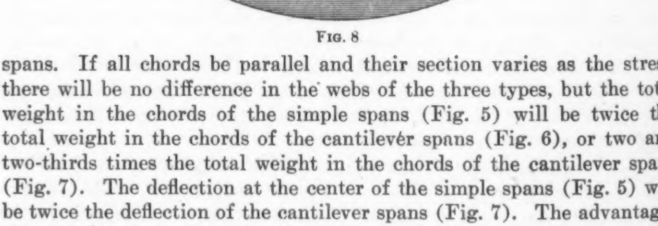

FIG. 8

spans. If all chords be parallel and their section varies as the stress, there will be no difference in the webs of the three types, but the total weight in the chords of the simple spans (Fig. 5) will be twice the total weight in the chords of the cantilever spans (Fig. 6), or two and two-thirds times the total weight in the chords of the cantilever spans (Fig. 7). The deflection at the center of the simple spans (Fig. 5) will be twice the deflection of the cantilever spans (Fig. 7). The advantages claimed for the arch, that the function of the bottom chord is performed by the abutments; and, for the suspension bridge, that the function of the top chord by the pull of the cables of the side spans, do not make up for the rational method in which the "cantilever principle" performs its work. Fig. 8 represents an arch bridge; Fig. 9 a

Mr. Chapman.

suspension bridge; and Fig 10 a cantilever bridge. The shaded portions of the moment diagrams in Figs. 8, 9, and 10 represent the moments resisted by each structure. The disadvantage of the arch in this respect is at once shown; the cantilever bridge resists the least bending moment. It will be noted, in the arch and suspension bridges, that the contours of the arch-rib and cable correspond to the bending moment, which is true only under the most favorable condition. Assuming a load of 1 lb. per lin. ft. of the 1 800-ft. span, we obtain an external bending moment at mid-span of 405 000 ft-lb.

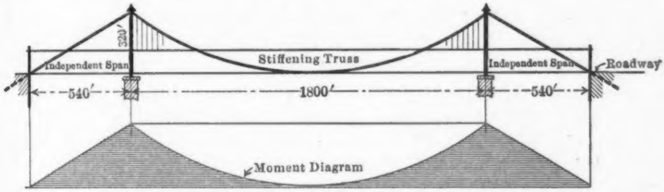

FIG. 9.

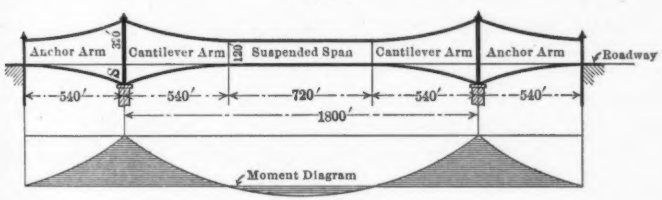

FIG. 10.

Comparing the summation of the horizontal component of the stress in each chord multiplied by its horizontal projection, we have, for the arch (or the suspension bridge) 2 280 000 ft-lb.; for the cantilever bridge 2 270 000 ft-lb.; which demonstrates that more material is required to carry the direct thrust of the arch than for the top and bottom chords of the cantilever bridge. It is apparent that when the additional material required in the arch, on account of temperature stresses, excess stresses due to partial live loads, excess wind stresses due to the shape of the arch, excess dead-load stresses due to the fact that the heaviest portion of the arch is in the center (therefore causing greater bending moment), is added, the material required for the chords of the arch-ribs is largely in excess of that required for the cantilever bridge chords. It is possible to design a cantilever bridge so that the web members resist a large portion of the bending moment, vertical members being omitted wherever possible, as they simply add weight and perform none of the work of transferring the load to the abutments.

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That the stresses in the webs of the arch are high, may be shown by reference to Fig. 3: assume the right half of the arch under the live load of 8 tons per ft.; the vertical reactions for live load at the supports become 1 800 tons and 5 400 tons, respectively; at the center of the arch, where the chords are parallel, the entire reaction of 1 800 tons is carried in the webs. This produces a stress in the webs, *R*, of 2 500 tons (both ribs). Partial loads and temperature changes would produce change in the angles, *d* and *e*, which would mean either high bending stresses in *D* and *E*, or movement on the pin, with consequent wear of the same. The movement of the chords in the cantilever bridge at *S*, under live load, would be relatively small, so that a pin might not be necessary. The writer believes that the erection of the cantilever bridge could be accomplished without appreciable secondary stress at the base of the tower, *S*, by erecting the tower first, and then balancing the erection of the cantilever and anchor arms, finally adding counterweights to the end of the anchor arm, as the erection of the suspended span proceeded. In this manner the tower could be kept plumb and true with no secondary stress, except under live load. Although the arch bridge has no towers, a study of all vertical and inclined members shows that in the arch and cantilever types, the summation of the vertical components of the stresses multiplied by the lengths is nearly equal for the 1 800-ft. spans, when half of the towers of the cantilever spans are considered therein. The suspension type, when compared in this respect, shows a larger result.

What study the writer has given, forces him to the conclusion that where conditions are similar to those cited by the author, the cantilever bridge is most advantageous. In conclusion, it might be well to remember that theoretically, with a given height of truss, the length of span of an arch, or a suspension bridge, is limited by the quality of the material, whereas the length of a cantilever bridge is limited only by the quantity of material.

Mr. Grimm.

C. R. Grimm, M. Am. Soc. C. E. (by letter).—Mr. Miller's statements referring to points made by the author are fully answered by the paper itself, and facts contradictory to those stated in the paper were not forthcoming. The remainder of Mr. Miller's discussion is devoted to repetitions of what has been often said and answered in the past; but without throwing a single additional ray of light on that subject.

Mr. Moisseiff states that the author's predilection for the arch is evidently based on estimates of weights, but he fails to produce the evidence. As a matter of fact, a statement in the paper—as to weights and the aim of the author—which should have put him right in this matter, he ignores.

In order to avoid any misunderstanding, it should be expressly

Mr. Grimm.

remarked that the paper assigns to esthetics a subordinate position, and in terms admitting of no contradiction.

A railroad suspension bridge, taken in the sense of that of the paper, that is, a bridge carrying the traffic of a railroad under no restrictions, exists only in the realm of dreams; it has never existed in reality, and, consequently, Mr. Moisseiff should have restricted his comparison to cantilever and arch bridges.

Numerous very notable bridges of the latter type are in existence, the greatest length of span being that of the four-track railroad arch to be built across Big Hell Gate in New York, which is about 1 000 ft. No engineer will be so rash as to say that cantilever and suspension bridges of very long spans are at the height of perfection, or that they cannot possibly be surpassed under any conditions by some other type of bridge.

The assertion that the writer fails to be convincing in his paper requires an explanation. The subject of arches is very difficult, in part highly mathematical, and, in its various aspects, very extensive. These elements offer very formidable obstacles to a ready and general acceptance of many statements in the paper, and these obstacles are increased by premature judgments, prejudices—sometimes deep-seated—and mistrust about everything which either is or appears to be new. To give, in a short, non-mathematical paper, under these conditions, a convincing demonstration of all that has been said and for every reader is simply impossible. One might just as well attempt to write a dissertation of a few pages, overcoming all obstacles—mathematical and otherwise—in order to demonstrate convincingly that non-Euclidean geometry directly contradicts Euclidean geometry, and that the former, nevertheless, is perfect and just as consistent and logical as that of Euclid, which has been taught for more than two thousand years.

The aim of the paper is to call to the attention of engineers the excellent qualities of arch ribs for long spans, and to create an interest in them, which will result in thorough investigation from every point of view, and finally in their use if conditions are favorable. If, after a severe examination, the arch rib is found wanting, then is the time to reject it, but not before. The writer selected a length of span which is approximately the limit used anywhere, but most spans, of course, are considerably less, a circumstance which is without influence on the contents of the paper.

Mr. Moisseiff's far-reaching requirements would necessitate a very elaborate discourse on the quality of the designs of the bridges before a discussion of their weights could be thought of. Sufficient data for an approximate check calculation have been given, and these provide the best means for a discussion of tonnages. His prompt rejection of the weights is a procedure which is as easy as it is effective to close the discussion on this point.

Mr. Grimm.

The assumption of nickel-steel throughout has been made for the sake of convenience, and it is not a point of discussion.

The best and only way to determine the effects due to temperature changes and yielding of masonry on statically indeterminate structures consists in the application of exact methods of calculation; all others are objectionable in the present case. Arch bridges have neither back-stays nor anchor chains, and analysis proves the suspension bridge to be more sensitive to the effects mentioned than an arch bridge. The matter under consideration leads to the remark that if the assumption of fixity of foundations for all practical purposes is unjustifiable, common sense dictates the assumption of a very liberal amount of yielding of the foundations, in order to determine its effect on the entire bridge and build it in accordance with the results thus obtained. This is good practice.

Mr. Moisseiff's idea of the deflection of a chain bridge compared with that of an arch rib is far from being true, and his dismissal of the deflection of a cable bridge with the remark that it is due only to the higher stress used for the cable wire sounds more like an excuse than anything else. Investigations would show that it requires all the resources at the command of the engineer to reduce the distortions of a railroad chain, or cable, bridge. Moreover, it is of no use to compare an arch with a fancied structure like an eye-bar suspension bridge having a truss as deep as that of an arch rib. That bridge would have towers about 550 ft. high, weighing, with anchor chains and anchor platforms, in the neighborhood of 30 000 tons if of carbon steel; and this enormous tonnage is principally required merely as a support for the bridge proper. Where does economy come in?

The Manhattan Bridge over the East River at New York City is a cable suspension bridge with a main span of 1 470 ft. and two side spans each of 725 ft. Ralph Modjeski, M. Am. Soc. C. E., in his report on that bridge, states*:

"Congested live load was assumed at 4,000 lbs. per ft. on each cable. By loading one side of the bridge with congested load it would be possible to obtain a load of 4,500 lbs. per ft. on the outside cable and the stresses in the tower would thereby be increased by from 4.5 to 5%. I do not think that the specifications could be interpreted to require such abnormal positions of load, otherwise by loading one side of the main span and the other side of both end spans the difference in deflection at the center of the main span between the two outside cables would be about 15 ft., producing a transverse grade of over 15%."

This statement furnishes an illustration of the fact that the writer's remark respecting the great care necessary in the design of railroad suspension bridges was quite proper—a remark with which Mr.

* *Engineering News*, October 14th, 1909.

Mr. Grimm.

Moisseiff does not agree. One of the many conditions to be fulfilled by a railroad bridge consists in carrying its live load, for any positions whatever, without violent distortions. With chords intersecting at the springing line, and a proper but not excessive depth at the center, that at the quarters of a sickle-shaped truss meets all requirements. It is hardly necessary to say that the chords do not need to intersect; they can be spread to any amount the designer sees fit. The distortions of a properly designed crescent arch are moderate for the most critical position of the load which is not full load.

The collapse of an arch by a supposed failure of the river piers, as an answer to the illustration in the paper, which shows that under certain extreme conditions a suspension bridge would fail while an arch bridge would stand, is meaningless. Why not, by way of extension, assume a limitless destruction and be through with it?

A careful reader cannot fail to find Mr. Moisseiff's references to the safety of a suspension bridge and the economy of an arch bridge with cable fully answered by the statements on erection in the paper.

As to the Loschwitz Suspension Bridge, the writer wishes to state that it was designed by distinguished engineers, and it would be a mistake to believe that the question of counterweights to reduce a thrust can be disposed of by a single quotation. The writer does not, by any means, intend to criticize Professor Mehrtens, but believes that he did not mean to disapprove, once and for all, of arrangements intended to reduce the thrust of an arch. He does not believe so, for the simple reason that Professor Mehrtens elsewhere* expresses the opinion, in referring to the Loschwitz Suspension Bridge, that an artificial limitation of the thrust was unnecessary on account of safety. In the source from which this opinion is taken Professor Mehrtens also states, quite in general, that artificial loading should be limited to local cases which make its use a necessity. Further, Professor Melan, who is known to American engineers on account of his writings on suspension bridges, has proposed counterweights without cables in connection with arches and intended to reduce their thrust. A description of this construction is found in "Handbuch der Ingenieurwissenschaften." There is no difficulty in enlarging on this subject.

Without even a shadow of an estimate of costs, Mr. Moisseiff's assertion that counterweights are necessarily expensive is wild guessing. It only remains to be noted that the writer proposed counterweight and cable for the express purpose of erecting an 1 800-ft. arch span, and not as an artificial provision for the arch thrust, a difference of purpose completely ignored by Mr. Moisseiff.

Anchorages, in their entire length, including the anchor platforms, which shall be open to inspection, are by no means as easily built as

* "Der deutsche Brückenbau im XIX. Jahrhundert."

Mr. Grimm. Mr. Moisseiff seems to think. Although opinions differ as to the desirability of inaccessible anchorages, the fact stands out prominently that anchorages which allow at any time a thorough inspection of all their parts offer a far greater degree of safety for a bridge than those which are inaccessible to inspection.

Mr. Moisseiff's discussion has failed to bring out a single point backed up by substantial statements against the fitness of arch ribs for very long spans.

Mr. Engesser remarks that a stiffening truss of the same great depth as that of the sickle would not collapse under the assumptions stated in the paper. This is true if the assumption respecting the tonnage—which shall not be essentially changed in either case, according to the paper—is disregarded; but the chances to build a stiffening truss 180 ft. deep are practically *nil.*

The esthetic influence of a cable on a steel rib, or the esthetic appearance of a through arch, are of minor importance compared with engineering and economical requirements.

The writer regrets that some of his statements have misled Mr. Krohn when he refers to masonry and erection in an economical sense, for the paper states:

"In the nature of things, the design of a bridge must first fulfill all necessary technical and economical requirements before the esthetic side of the problem is taken up," etc.

"All technical and economical requirements" certainly include considerations of masonry and erection. The importance of erecting an 1 800-ft. span is fully appreciated, as is shown by the proposal of a cable in connection with a steel rib. These cables are intended to effect the erection more economically, and to reduce the difficulties; and, moreover, they insure some other advantages. Bridge *C* requires less shore masonry, and it can be erected in a less expensive manner. This manner may consist in erecting the 1 000-ft. span as a guyed cantilever and using a cableway with its towers 1 800 ft. apart on top of the cantilever trusses.

The quantities of masonry are variable in a high degree, under different circumstances, and it was intentional that they were not considered in the paper, which is confined to comparisons of superstructures.

Another sentence of the paper reads:

"The superiority of the crescent rib over other forms of trusses in certain cases should prompt an engineer to give it careful consideration."

This means that a steel rib cannot be used with advantage in all cases and under any circumstances.

The writer takes the same general view as Mr. Krohn, when he states that not all arch bridges should be designated as beautiful, as

is shown by his criticism of a long-span spandrel arch. On the other hand, opinions may differ in reference to Bridge *C*, which Mr. Krohn does not find esthetically satisfactory to his taste. If Mr. Krohn's statement were accompanied with some reasons for his judgment, the charge could be answered in detail, but, as the statement stands, a general remark may suffice. The sketches, *A*, *B*, and *C*, are intended merely to indicate the nature of the structures, and their configurations could be very essentially changed by a designer as dictated by necessity and opinion—technical and esthetical. Apart from this, there is no doubt that a 1 000-ft. sickle gives the desired esthetic effect, but when elevated and carried by massive cantilever arms in a way and manner free from any disguise and subterfuge, the esthetic effect is enhanced and the structure is at least expressive of the most powerful energy. Doubtless some designers would not be able to resist the temptation to disguise the hinges of the arch, thus concealing the true character of the bridge. **Mr. Grimm.**

Mr. Buck's discussion shows a total lack of familiarity with the subject of the paper, which causes him to turn to denials as a relief. His failure to grasp the true meaning of its principal statements has resulted in the grossest violations of the truth. In his blind zeal to condemn the entire paper, it is amusing to see him fall into the very trap of false generalizations and deductions made without analysis against which he warns. Inveighing is by no means legitimate criticism, for the latter is desirable and useful. The author cannot be expected to write a long treatise, inclusive of mathematical discussions, for the purpose of enabling Mr. Buck to see things in their true light.

Mr. Lindenthal is laboring under an erroneous idea if he thinks that a bridge such as described in the paper, and governed by the specifications given, can be built with 30 000 tons of steel. This cannot be done, no matter what the nature of its design. A demonstration of the error in Mr. Lindenthal's calculation is unnecessary, and this quite apart from the circumstance that the subject is not important enough to warrant it.

If no objections are raised to marked disadvantages, other than great weights, which make an eye-bar suspension bridge inferior to a cantilever bridge, its greater tonnage would answer the purpose, if weight is the important end in a bridge with a main span of 1 800 ft. On the other hand, if any particular but satisfactory design should require a tonnage considered lower than is good for a very long span, the tonnage can be raised to any desired amount with the greatest facility, increasing also the strength of the structure.

The paper clearly points out that, not only other truss types are worthy of study, but also other trussed arch bridges which deliver the thrust against the shore masonry instead of against the river piers,

Mr. Grimm.

and are essentially different from those considered, but not investigated by the author. To quote from the paper:

"The writer's principal aim consists in laying before the reader the principles involved in these structures, rather than their weights."

These statements refute Mr. Lindenthal's idea of a search for something light, for that would require an examination of very many designs not undertaken by the writer. The esthetic question raised by him is partly answered by the writer's reply to Professor Krohn. Bender's design pretends to be a continuous arch of 1 700 ft., which it is not. A judgment as to intended deceptions is left to the reader.

Mr. Jonson makes an attempt to state what constitutes art, but his explanations do not satisfy the requirements of a bridge engineer, and his discussion is only significant by its confusion. According to him, principles of art cannot be used safely, and beauty is governed by certain laws. But, as principles signify laws, he involves himself in a contradiction. He asserts that symmetry is by no means a universal characteristic of good architecture. The paper does not assert that it is. Symmetry is not always a matter of importance for an esthetic object, it may even be wanting, without loss in esthetic effect, but, for a bridge, it is of consequence. There are, for example, countless beautiful landscapes in existence, none of which is symmetrical, but neither they, nor an Ionic temple in Greece, or a cathedral in France, are under discussion. An odd number of openings he admits as good architecture, with exceptions to this rule, although previously he asserts that art cannot be formulated in rules. Moreover, the exceptions he has in mind have nothing to do with the subject of the paper.

Mr. Jonson's reference to uniform length of spans is a matter of engineering, and is not under discussion, but the esthetic appearance of a bridge is a matter of secondary importance, as pointed out in the paper. If this latter must be considered, a decrease in the length of the spans, from the middle toward the ends, is proper.

No bridge engineer needs an explanation of why the floor in Bridges *A, B,* and *C* does not pass over the crowns of the arches.

Mr. Jonson does not state what has led him to the opinion that the most beautiful arches are those which approach the semicircle. As a matter of fact, a great rise reduces the expression of energy, and, consequently, also the esthetic effect.

An artist is supposed to be gifted with a vivid imagination, and, therefore, it is not strange to see the discussor establish the identity between the nature of art and mechanical principles by means of the paper, which, in plain language, excludes a scientific explanation of the esthetic phenomenon.

Mr. Jonson's standpoint is fully characterized by the following sentence from his discussion:

"In the past, most bridges were arch bridges; hence this type has reached the highest artistic development, and has accordingly been most highly appreciated, but this does not prove that in the future the suspension bridge and the truss bridge may not reach the same artistic level." Mr. Grimm.

Artistic development may raise a basket to the level of a beautiful headgear, but it cannot perform miracles. Artistic development, taste, style, graceful lines, architecture, or whatever it may be called, will never succeed in lifting the simple truss bridge from its original low level. This bridge is, and remains, a lintel, and, consequently, a dead structure; while activity and energy find the highest expression in a bridge with pure arch ribs, and these elements are of prime consequence for intense esthetic effect. The deep esthetic impressions, for instance, made upon us by a display of power and energy, be it in Nature on the grandest scale or in art, can neither undergo a change nor are they due to "esthetic habit" as Mr. Moisseiff intimates. Such ideas do not touch that which is fundamental. The esthetic phenomenon leads deep down into human nature, and only with a change of the latter could the effect made by the outer world upon the senses and the intellect be altered.

The writer is pleased to learn that such eminent engineers as Messrs. Engesser and Krohn thoroughly agree with him in all essential points as to his estimation of long-span steel ribs in their various aspects. He has also proof that there are other engineers of the highest standing who share the same view with him on this subject—minor points disregarded—which has never been given that degree of attention in America which it fully deserves.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1186

A THEORY OF THE WATER WAVE.

By Morton F. Sanborn, Assoc. M. Am. Soc. C. E.

While studying the vertical circulation of the water in the Charles River Basin,* near Boston, Mass., the writer thought that there must be a simple theory of wave action, and so has undertaken to find that theory, the results of his conclusions being contained in the following paper.

No attempt has been made to go into the deeper mathematical problems connected with the theory; only a general statement that may be useful to engineers is given here.

The writer has not been able to do much experimental work; but has secured his data largely from a paper† by Captain D. D. Gaillard, now Lieutenant-Colonel, Corps of Engineers, U. S. Army. Captain Gaillard's paper contains a large amount of information, obtained from his own experiments and from other sources.

The following theory is based on the fact that water will move in the direction of least resistance, following the law that a column of water in a bent tube will oscillate up or down in one side in the same time that a pendulum, which is one-half the length of the column of water, will swing; the theory is also based on other well-known facts and laws.

* "Distribution of Sea Water in the Charles River Basin After Excluding Tidal Waters," *Engineering News*, March 10th, 1910.

† "Wave Action in Relation to Engineering Structures," Professional Paper No. 31, By Captain D. D. Gaillard, Corps of Engineers, U. S. Army.

The theory that the motion of the particles of water in a wave is in a circle or ellipse, and even approaches a straight line, for waves in shallow water, is accepted, as all experiments have shown that to be the case.

Theory of Motion of Deep-Water Waves.

Fig. 1 represents a trough, *AB,* with a gate, *CD,* which can be raised. The water stands at the height, *H,* on the left of the gate and

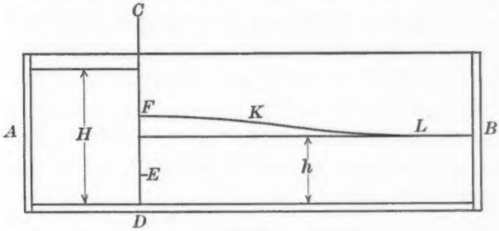

Fig. 1.

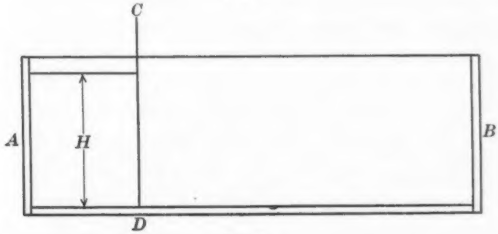

Fig. 2.

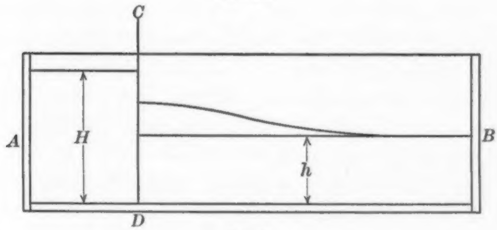

Fig. 3.

at the height, *h,* on the right. When the gate, *CD,* is raised so that the bottom will be at *E* the water at the left of the gate will settle down, some of it flowing out under the gate, raising the water on the right, and causing it to take a form somewhat like *FKL.*

The water at the left of the gate will settle until it has lost its motion, as in the bent tube, then it will rise again, and keep falling and rising until the resistance has overcome the power of motion, and the water will stand level in the trough. This action will be called one of displacement, where the motion is communicated through the water to water at a distance.

Fig. 2 is the same trough with no water on the right of the gate. When the gate, *CD,* is raised clear of the trough, the water to the left will flow toward the end, *B.* This action will be called one of flow.

In Fig. 3 there are the same conditions as in Fig. 1, but when the gate, *CD,* is lifted clear of the trough, the resulting action is one of both flow and displacement, and the result is a wave, the flow starting immediately, and the action is similar to that in the crest of a wave. The displacement is felt in advance of the crest, and is shown by the upward motion of the water. The motion of the particles of water in a wave is due to the resultant of these two forces, namely: By flow, which gradually decreases while the displacement or vertical motion increases, and then the reverse action.

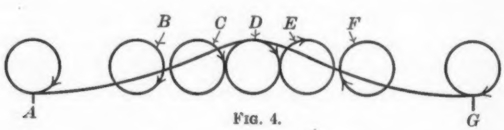

FIG. 4.

Although the forces that act on the particles of water in a wave are of flow and displacement, they are also dependent on the action of every other particle in the complete wave, and it is their united action which produces the regular waves seen after a storm.

Whether the wave is caused by the wind or by some object placed in the water, it is forced to go away from the disturbance just the same as in the case of the trough.

Fig. 4 shows the direction of motion of the particles of water on the surface of a complete wave:

Particle *D* is affected only by flow, so that it travels horizontally and not vertically, as it has lost its upward motion and has not acquired a downward motion.

Particle *E,* being in advance of the highest part, has not yet acquired its full flow, and, as it is approaching the highest position,

has lost some of its upward velocity; the resultant is shown by its position on the circle.

Particle F is so far in advance of the crest that it is not affected much by flow, and, being about half-way up, has attained its greatest upward velocity.

Particle C, the crest of the wave having passed, has acquired some velocity in a downward direction. It cannot fall in a vertical direction, on account of the horizontal motion given to it when at the top of the wave, and as the wave may be traveling at a uniform velocity of 20 or 30 ft. per sec., the water, to acquire that velocity in a downward direction, would have to separate itself from the wave and fall independent of it.

Particle B is half-way down, and has acquired its greatest downward velocity, but has no horizontal motion, as it is beyond the effect of the wave just passed.

The motion of Particle A is similar to that of G, as they are at the same point of the wave. They are at the lowest point in the trough of the wave, and therefore have no vertical motion. Their horizontal motion is about the same as when in the crest, but in the opposite direction, caused by suction to fill the positions left by Particle F and to make room for Particle B.

Velocity.—An examination of the movement of the particles of water in a wave shows that the half nearest the crest is moving forward, while the half in the trough is moving backward. At the points of meeting of these two movements there is vertical, but no horizontal, motion.

It is also seen that the half of the wave from the crest to the trough in front is moving upward, while the half from the crest to the trough in rear is moving downward, and it is this one-half length of the wave that is the base of the following formulas.

The number of seconds, T, required by water in a bent tube to rise or fall in one side is found by the following formula:

$$T = \frac{\sqrt{\frac{L}{2} \times 12}}{\sqrt{39.1}} \quad \text{.....................} (1)$$

In which T = the time, in seconds; and L = the length of the column of water, in feet.

Applying this formula to a wave gives:

$$T=\frac{\sqrt{\frac{L}{4}\times 12}}{\sqrt{39.1}},\ \text{or } 0.277\sqrt{L}\ \ldots\ldots\ldots\ldots\ldots\ (2)$$

In which L = the longitudinal length of the wave, in feet; and T = the time, in seconds, required by a particle to rise or fall.

The velocity of the wave is found by the formula:

$$V=\frac{L}{T}=\frac{\frac{L}{2}}{\frac{\sqrt{3\,L}}{\sqrt{39.1}}}=\frac{L\sqrt{39.1}}{2\sqrt{3\,L}}=1.804\sqrt{L}\ \ldots\ldots (3)$$

The trochoidal formula for the velocity of a wave is:

$$V=\frac{\sqrt{g\,L}}{2\,\pi}=\sqrt{g\,R}=\sqrt{5.123\,L}\ \ldots\ldots\ldots\ldots (4)$$

In which g = the acceleration due to gravity, in feet per second;
L = the horizontal length of wave, in feet; and
R = the radius of the rolling circle, in feet.

For better comparing the two theories, the observed and computed velocities, taken from Table 1, were plotted on Fig. 5. The circles represent the observed lengths of waves and their velocities. The upper curve is the theoretical velocity, as determined by the trochoidal formula. The two lower curves were obtained from Formula 3, and represent the theoretical velocity.

It will be noticed that the trochoidal curve goes through the upper part of the observed velocities, while the curve by Formula 3 passes through the lower portion.

If a pendulum, with the best of bearings, is placed in a vacuum as nearly complete as possible, and started swinging, it will keep nearly perfect time for a few hours, or until the motion has stopped.

After a big storm, over deep water, it is many hours after the wind has stopped blowing before the wave motion has ceased. Why should not the deep-water wave keep as good time as the pendulum? Attention is again called to the fact that in Fig. 5 the theoretical velocity by Formula 3 passes through the lower part of the observed velocities.

Fig. 6 shows a pendulum at rest, with an air pipe and nozzle, *B*, and a valve, *C*, which shuts off the air current. By allowing the air

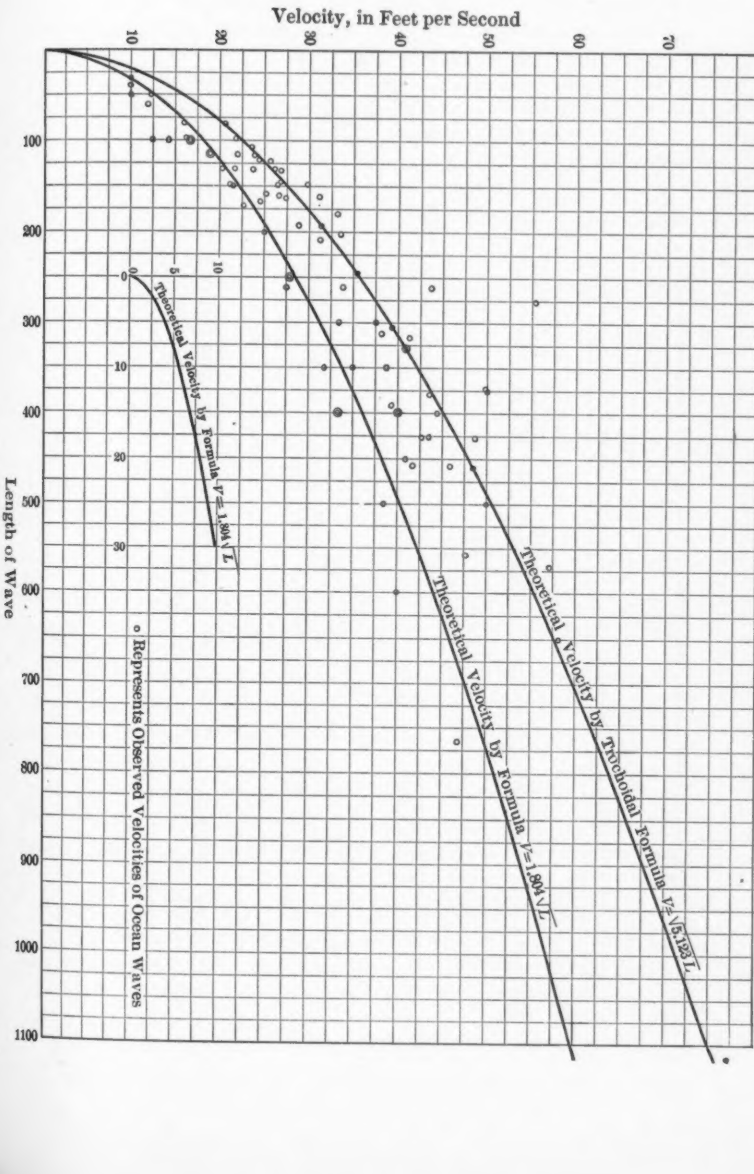
Velocity, in Feet per Second
10
20
30
40
50
60
70
Length of Wave
100
200
300
400
500
600
700
800
900
1000
1100
0
5
10
20
30
Theoretical Velocity by Formula $V=1.804\sqrt{L}$
Theoretical Velocity by Formula $V=1.804\sqrt{L}$
Theoretical Velocity by Trochoidal Formula $V=\sqrt{5.123\,L}$
∘ Represents Observed Velocities of Ocean Waves

FIG. 5.

TABLE 1.—COMPARISON OF OBSERVED VELOCITIES OF DEEP-WATER WAVES WITH THAT COMPUTED BY THE TROCHOIDAL THEORY AND BY FORMULA 3.

Wave height.	Wave length.	WAVE VELOCITY, IN FEET PER SECOND.				
		Observed.	Computed: $V=\sqrt{5.123\ L}$	Difference, columns (3) and (4).	Computed: $V=1.804\sqrt{L}$	Difference, columns (3) and (6).
(1)	(2)	(3)	(4)	(5)	(6)	(7)
24.6	1 121	77.3	75.8	— 1.5	60.4	—16.7
46.0	765	46.4	62.5	+16.1	49.9	+ 3.5
36.1	650	58.0	57.6	— 0.4	46.0	—12.0
37.5	600	40.0	55.4	+15.4	44.2	+ 4.2
13.1	571	57.1	54.1	— 3.0	43.1	—14.0
43.0	559	47.7	53.5	+ 5.8	42.6	— 5.1
25.0	500	38.5	50.6	+12.1	40.3	+ 1.8
4.0	500	50.0	50.6	+ 0.6	40.3	— 9.7
19.7	460	48.5	48.5	0.0	38.7	— 9.8
24.6	459	41.7	48.4	+ 6.7	38.6	— 3.1
14.4	459	45.9	48.4	+ 2.5	38.6	— 7.3
25.0	450	40.9	47.9	+ 7.0	38.3	— 2.6
26.2	428	48.2	46.8	— 1.4	37.3	—10.9
11.5	426	42.6	46.6	+ 4.0	37.2	— 5.4
9.8	426	43.5	46.6	+ 3.1	37.2	— 6.3
24.0	400	33.3	45.2	+11.9	36.1	+ 2.8
22.0	400	40.0	45.2	+ 5.2	36.1	— 3.9
21.0	400	44.4	45.2	+ 0.8	36.1	— 8.3
18.0	400	33.3	45.2	+11.9	36.1	+ 2.8
8.0	400	40.0	45.2	+ 5.2	36.1	— 3.9
21.3	394	39.4	44.9	+ 5.5	35.8	— 2.6
14.8	394	49.2	44.9	— 4.3	35.8	—13.4
32.0	380	43.6	44.1	+ 0.5	35.2	— 8.4
25.0	375	50.0	43.8	— 6.2	34.9	—15.1
33.6	374	49.9	43.7	— 6.2	34.9	—15.0
23.0	350	35.0	42.3	+ 7.3	33.7	— 1.3
16.0	350	38.9	42.3	+ 3.4	33.7	— 5.2
16.0	350	31.8	42.3	+10.5	33.7	+ 1.9
21.0	328	41.9	40.9	— 0.1	32.7	— 8.3
14.8	328	41.0	40.9	— 0.1	32.7	— 8.3
6.6	328	44.6	41.0	— 3.6	32.7	—11.9
18.0	318	42.4	40.3	— 2.1	32.2	—10.2
5.0	314	38.1	40.0	+ 1.9	31.9	— 6.2
8.2	305	39.4	39.5	+ 0.1	31.5	— 7.9
18.0	300	37.5	39.1	+ 1.6	31.2	— 6.3
15.0	300	33.3	39.1	+ 5.8	31.2	— 2.1
12.0	276	55.2	37.5	—17.7	30.9	—25.2
19.7	262	27.6	36.6	+ 9.0	29.2	+ 1.6
8.2	262	43.7	36.6	— 7.1	29.2	—14.5
5.0	261	33.9	36.5	+ 2.6	29.1	— 4.8
18.0	250	27.8	35.7	+ 7.9	28.5	+ 0.7
15.0	250	27.8	35.7	+ 7.9	28.5	+ 0.7
8.0	249	35.6	35.7	+ 0.1	28.5	— 7.1
10.5	209	31.2	32.7	+ 1.5	26.1	— 5.1
14.8	202	33.5	32.2	— 1.3	25.6	— 7.9
15.0	200	25.0	32.0	+ 7.0	25.5	+ 0.5
13.1	193	28.9	31.5	+ 2.6	25.1	— 3.8
8.0	191	31.3	31.2	— 0.1	24.9	— 6.4
11.1	180	32.7	30.3	— 2.4	24.2	— 8.5
8.0	171	22.8	29.6	+ 6.8	23.6	+ 0.8
11.0	167	24.6	29.2	+ 4.6	23.3	— 1.3
11.5	164	27.3	28.9	+ 1.6	23.1	— 4.2
2.6	162	31.2	28.8	— 2.4	23.0	— 8.2
14.0	160	26.7	28.6	+ 1.9	22.8	— 3.9
6.6	158	25.1	28.4	+ 3.3	22.7	— 2.4
15.0	150	21.4	27.7	+ 6.3	22.1	+ 0.7
11.5	148	21.1	27.5	+ 6.4	21.9	+ 0.8
9.8	148	26.4	27.5	+ 1.1	21.9	— 4.5

TABLE 1.—(*Continued.*)

Wave height. (1)	Wave length. (2)	Wave velocity, in feet per second. Observed. (3)	Computed: $V=\sqrt{5.123\ L}$ (4)	Difference, columns (3) and (4) (5)	Computed: $V=1.804\sqrt{L}$ (6)	Difference, columns (3) and (6) (7)
4.6	148	29.8	27.5	− 2.3	21.9	− 7.9
8.2	145	26.9	27.3	+ 0.4	21.7	− 5.2
3.9	134	26.9	26.2	− 0.7	20.9	− 6.0
8.2	131	20.2	25.9	+ 5.7	20.6	+ 0.4
8.2	131	23.8	25.9	+ 2.1	20.6	− 3.2
7.5	131	21.7	25.9	+ 4.2	20.6	− 1.1
4.9	131	26.2	25.9	− 0.3	20.6	- 5.6
6.6	123	25.6	25.1	− 0.5	20.0	− 5.6
3.3	119	24.3	24.7	+ 0.4	19.7	− 4.6
8.9	115	19.2	24.2	+ 5.0	19.3	+ 0.1
7.5	115	19.2	24.2	+ 5.0	19.3	+ 0.1
4.6	115	24.0	24.2	+ 0.2	19.3	− 4.7
3.6	115	22.1	24.2	+ 2.1	19.3	− 2.8
2.6	108	23.6	23.5	− 0.1	18.7	− 4.9
8.0	100	14.3	22.6	+ 8.3	18.0	+ 3.7
7.0	100	16.7	22.6	+ 5.9	18.0	+ 1.3
6.0	100	16.7	22.6	+ 5.9	18.0	+ 1.3
4.0	100	12.5	22.6	+10.1	18.0	+ 5.5
6.6	98	16.3	22.4	+ 6.1	17.9	+ 1.6
4.9	98	21.8	22.4	+ 0.6	17.9	− 3.9
4.3	82	20.5	20.5	0.0	16.3	− 4.2
6.0	80	16.0	20.2	+ 4.2	16.1	+ 0.1
5.0	60	12.0	17.5	+ 5.5	14.0	+ 2.0
4.0	50	10.0	16.0	+ 6.0	12.8	+ 2.8
3.0	50	12.5	16.0	+ 3.5	12.8	+ 0.3
2.0	40	10.0	14.3	+ 4.3	11.4	+ 1.4
3.0	30	10.0	12.4	+ 2.4	9.9	− 0.1

The first five columns of Table 1 are taken from Table XI of Captain Gaillard's paper, and the last two columns were calculated by the writer. Captain Gaillard's observations were taken by eleven different sets of observers on forty-one different dates.

to flow and then shutting it off, the pendulum is started swinging; and, if the valve is opened while the pendulum is moving from left to right and closed for the rest of the time, the pendulum will keep up its swinging.

If the pendulum is well pivoted, the air as it strikes the ball will give it a little more force each time, causing it to swing higher and higher until it finally makes a complete circle, and as the air continues blowing on the ball it will go around faster and faster until the air current is just sufficient to overcome the friction.

Before the pendulum made the complete turn it kept fairly good time, considering the extra force given to it; but, after it made a complete turn, the time was reduced, and the number of revolutions depended on the air current.

When the air is shut off, the friction gradually reduces the time of revolution of the pendulum to that which would be swung by a pendu-

lum of like arm, and then it ceases to turn completely over and keeps the same time until it stops altogether.

This action is similar to that of a water wave. The wind blowing on the crest of the wave, forcing it ahead and downward, causes the wave to travel faster than the velocity called for by the length; but by Formula 3, the velocity is dependent on the length of the wave; therefore, as the wave travels faster, it will try to lengthen out horizontally. This cannot be done immediately, as it is kept in place somewhat by the wave in front and the wave behind, so that the re-

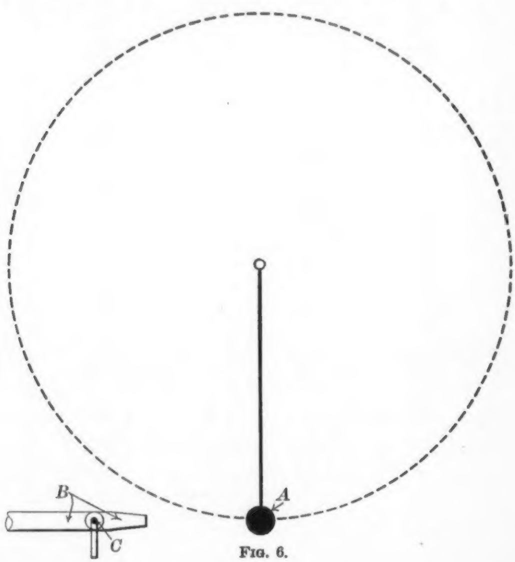

Fig. 6.

adjustment comes gradually. This adjustment may be accomplished by two waves uniting, one wave overtaking another, or as they run before the wind. If the wind should die out before the wave has readjusted itself, it would still take some time to do so.

When the wave has readjusted itself and the wind has stopped blowing, the friction gradually causes the wave to travel more slowly, which reduces the wave length.

A study of Table 2 shows that the greatest percentage of increase of velocity occurs when the wind has been blowing for a comparatively

short time; when the same wind velocity is maintained for a longer time the wave gradually lengthens out, which increases the theoretical velocity and reduces the percentage of increase.

TABLE 2.—INCREASE OF WAVE VELOCITIES ABOVE THE THEORETICAL, IN THE DULUTH CANAL, DUE TO THE WIND.

Date.	Length.	Mean depth.	MEAN WAVE VELOCITY, IN FEET PER SECOND.			HOURLY WIND VELOCITY, IN FEET PER SECOND.			Number of observations.
			Observed.	Computed.	Increase over theoretical.	During wave observations.	Maximum during 12 hours preceding.	Mean for 12 hours preceding.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1901.									
May 23...	180[a]	24.7-26.7	27.1	24.2	12%	48.2	80.7	57.5	39
June 14...	130	24.7-26.7	25.3	20.6	23%	49.1	55.9	29.6	20
September 24...	225[d]	24.7-26.7	27.7	27.0	03%	67.6	70.9	60.6	80
October 9...	145[b]	24.7-26.7	22.9	21.7	06%	42.2	49.1	28.6	30
November 6...	140[c]	24.7-26.7	28.7	21.4	34%	62.6	72.5	32.0	20
November 22...	150	24.7-26.7	25.3	22.2	13%	35.3	38.7	34.4	21
1902.									
August 15...	70	24.7-26.7	18.2	15.1	21%	29.0	31.8	18.0	3

[a] This length is the average of 160 and 200 ft.
[b] Tnis length is the average of 140 and 150 ft.
[c] This length is the average of 130 and 150 ft.
[d] This length is the average of 200 and 250 ft.

The wind velocities in this table are the corrected velocities, as determined by the United States Weather Bureau by a Robinson's anemometer located on the edge of a high bluff in rear of the City of Duluth, and 1.25 miles from the point of observation of the waves, the wind blowing in the direction of wave travel.

Columns 1, 4, 7, 8, and 9 were taken from Table XIV of Captain Gaillard's paper.

Columns 2, 3, and 10 were taken from Table X of Captain Gaillard's paper.

Column 5 was computed by Formula 3.

Column 6 gives the percentage of increase over the theoretical velocity.

These seven observations were the only ones that could be used from Captain Gaillard's Table XIV, as the lengths of the other observations varied too much to get a fair average. Although these may be considered as shallow-water waves, they show very well the effect of the wind.

In Formula 3 the writer has only considered the horizontal length of the wave; but it is possible that the true length for finding the period of a wave should be taken along the surface or along the filament, *OP,* which passes through the center of gravity of the volume of water contained in *ABF,* Fig. 7. This would give the wave a longer period and slower velocity.

A study of Table 1 shows that most of the waves having a velocity slower than the theoretical are high waves; and, with waves of the same length, the highest are generally the slowest.

There are so many conditions that enter into the formation of a wave that the writer has not considered this refinement necessary, for,

by using the horizontal length, the maximum theoretical velocity is obtained.

Depth to Which Wave Action Extends.—Fig. 7 shows regular waves, 100 ft. long and 10 ft. high, that portion between *M* and *K* being a complete wave. Now, it can be seen that the quantity of water included between *JK* is larger than that between *MJ*, by the water contained in *JIKL*, and this excess must pass by the vertical line through *J* twice in every complete wave motion; once forward with the wave, and once backward in the trough. It will also be seen that the quantity of water contained in *JIKL* must pass by any vertical line, as *NF*, twice in each wave motion.

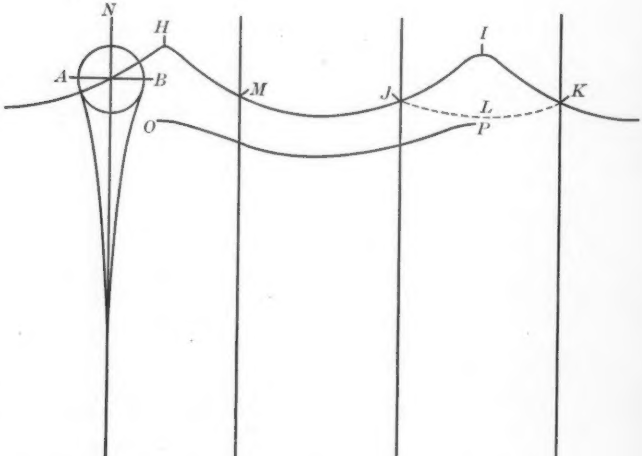

Fig. 7.

The motion of the particles of water on the surface is in a circle, with the height of the wave as the diameter. The motion below the surface decreases as the distance below the center of the surface orbits increases in arithmetical progression; the radii decrease in geometrical progression, this decrease being at such a rate that the area contained between the curved lines, *AF* and *BF*, joining the ends of the radii and perpendicular to them, is equal to the area, *JIKL*.

This gives a depth of wave action which is greater than is generally supposed. The depth could be decreased considerably without affecting the wave very much, as long as the changes are not so sudden that the wave could not readjust itself.

Shape of the Wave.—To plot the surface of a deep-water wave, lay off the length, AB, Fig. 8. Construct a circle tangent at A, with a diameter, AC, equal to the height of the wave. Divide AB into eight or as many equal parts as required, and erect perpendiculars. Divide the circumference of the circle into the same number of equal parts, and draw horizontal lines through these points. Let A be the lowest part of the wave. Next consider the particle, M, its center being one-eighth of the distance from A to B. It will be in the horizontal line drawn through D, and $\frac{AB}{8} + KD$ from K.

The particle, N, the center of which is one-fourth of the distance from A to B, will be in the horizontal line drawn through E, and $\frac{AB}{4} + EL$ from L. The particle, O, the center of which is three-eighths of the distance from A to B, will be in the horizontal line drawn through F, and will be $\frac{3\,AB}{8} + FH$ from H.

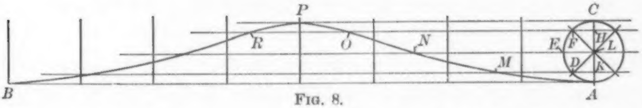

FIG. 8.

The particle, P, the center of which is one-half the distance from A to B, will be the top of the wave, and one-half the distance from A to B. The particle, R, the center of which is five-eighths of the distance from A to B, will be in the horizontal line drawn through F, and $\frac{5\,AB}{8} - FH$ from H. The rest of the wave should be plotted in a similar manner.

This surface wave is the same as that given by the trochoidal theory, but the writer prefers to consider it by his construction, as it is simple to understand.

It will be seen that the distance, AM, is greater than MN, and still greater than NO, showing that all the surface particles cannot have circles as their orbits; but that some of them must be forced under while others must be forced higher in the crest of the wave.

While this may not be the true shape of the wave, it is very close to it, and gives a quantity of water which is at least as much as that actually in the wave.

The shape of the wave at any point below the surface is shown in the same way, by using the same length of wave, but with a height corresponding to the diameter of the orbits at the depth taken.

All particles in a vertical line move in the same direction unless prevented by some outside action, such as the wind forcing the crest ahead, or friction on the bottom tending to retard the lower portion.

Height of the Wave.—The height of a wave is generally caused by the wind, and is modified by the depth of water and the "fetch," or open water from the windward shore. The wind, blowing unevenly on the water, causes the formation of depressions and ridges, after which the wind acts directly on the ridges or crests, forcing them ahead and downward. It has been seen that the back of the crest starts downward, and, with the added force of the wind, it goes a little deeper, and then, as it rises, it goes still higher than before.

The wind, causing the height, may also prevent the wave from going very high, as it may blow on the crest and force it to break or start downward before it has lost all upward motion.

It has also been stated that the height may have an influence on the period or velocity of the wave.

Wave Energy.—From Fig. 7 it is seen that the volume of water in the area, *JIKL*, moves forward and back in each complete wave, and that the same quantity must move forward in each wave crest. The volume contained in *JIKL*, considered as 1 ft. thick, may be approximately obtained by the formula:

$$V = \frac{L\,H}{4} \qquad \text{(5)}$$

In which L equals the length of wave, and H equals the height, both in feet.

This gives an energy of water moving forward with the wave, if taken 1 ft. wide, equal to the volume contained in the area, *JIKL*, multiplied by the velocity with which the wave is traveling, and may be found approximately by the formula:

$$\text{Energy} = \frac{V\,L\,H\,W}{4} \qquad \text{(6)}$$

In which V = the velocity of the wave, in feet per second;
L = the length of the wave, in feet;
H = the height of the wave, in feet; and
W = the weight of a cubic foot of water, in pounds.

This does not mean that the same water moves forward with the wave, but it is the force in the moving wave.

The energy is distributed throughout the half of the wave at the crest, and downward to the greatest depth of wave action.

Shallow-Water Waves.

Waves moving in water of a depth less than one-half the wave length have generally been called shallow-water waves, because the friction on the bottom modifies somewhat their shape and velocity.

Waves may move in water which is much shallower than one-half the wave length without materially affecting their velocity. It can be seen that, of two waves of equal length, but with one having a height of twice the other, the larger wave, having about twice as much water moving forward, will feel the effect of friction on the bottom more quickly.

Velocity.—It is the writer's opinion that Formula 3 may be used for all waves with a coefficient suitable for the conditions. The theoretical velocity has been shown and also the increase in velocity due to wind action in a few cases. The first effect on deep-water waves running in on a beach is to reduce the velocity. The wind causes the waves to travel faster, so that they have to lengthen out, while the friction on the bottom causes the wave to travel more slowly, which shortens the wave lengths, as will be shown later.

A study of Table 3 shows in general that when the wave height is more than one-half of the depth of water, the velocity is materially reduced below the theoretical; but, when the wave height is less than one-half the depth, the observed velocity is as great as the theoretical.

When the wave height is from one-half to one-third of the depth of water, it is probable that the velocity begins to be materially reduced, and if the water continues to grow more shallow, the velocity and wave length are reduced until the wave breaks.

On Fig. 9 has been plotted the observed lengths of the waves of Table 4, showing the percentage of the theoretical velocities; and a curve has been drawn through the averages, to give the percentage for any length under similar conditions.

TABLE 3.—HEIGHT, LENGTH, AND PERIOD OF WAVES OBSERVED IN THE DULUTH SHIP CANAL AND IN LAKE SUPERIOR, ARRANGED ACCORDING TO MEAN DEPTH OF WATER.

Date.	Heights, in feet.	Lengths, in feet.	Periods: Observed, in seconds.	Periods: Computed, in seconds.	Mean depth, in feet.	Number of observations.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Observations Taken in Duluth Ship Canal.						
1901.						
May 23	8.0-17.0	160-200	6.9-8.0	7.0-7.8	24.7-26.7	39
May 24	6.5- 8.0	130-150	6.0-7.5	6.3-6.8	24.7-26.7	3
June 14	9.0-12.0	130	5.1-5.8	6.3	24.7-26.7	20
June 15	2.0- 8.0	120-140	5.9-6.4	6.1-6.6	24.7-26.7	21
July 24	4.0-12.0	110-150	5.8-6.8	5.8-6.8	24.7-26.7	40
August 9	4.0-14.0	100-130	4.4-6.8	5.5-6.3	24.7-26.7	49
September 24	6.0-23.0	200-250	7.4-8.0	7.8-8.8	24.7-26.7	80
October 9	5.0-10.0	140-150	6.3-6.5	6.6-6.8	24.7-26.7	30
October 10	4.0- 9.0	150	6.8-8.3	6.8	24.7-26.7	20
November 6	6.0-13.0	130-150	4.9-5.4	6.3-6.8	24.7-26.7	20
November 22	7.0-16.0	150	5.5-6.4	6.8	24.7-26.7	21
1902.						
April 21	7.0-14.0	100-200	5.1-8.7	5.5-7.8	24.7-26.7	75
April 22	7.0-13.5	175-275	6.0-9.1	7.3-9.2	24.7-26.7	22
May 1	6.5-11.7	100-150	4.4-6.0	5.5-6.8	24.7-26.7	15
May 20	8.0-14.5	110-200	5.5-8.0	5.8-7.8	24.7-26.7	13
August 15	2.5	70	3.9	4.6	24.7-26.7	3
October 23	7.0-13.0	130-200	5.0-8.0	6.3-7.8	24.7-26.7	14
October 25	9.0-13.0	105-185	5.0-7.0	5.7-7.5	24.7-26.7	14
October 26	8.0-10.0	170-200	6.2-6.8	7.2-7.8	24.7-26.7	3
November 12	12.0-16.0	160-250	6.1-9.2	7.0-8.8	24.7-26.7	23
November 13	10.0-14.0	188-200	7.5-8.0	7.6-7.8	24.7-26.7	5
Observations Taken in Lake Superior.						
April 22	7.0-12.0	160-185	7.4 8.6	7.0-7.5	18.7	7
April 21	7.0- 9.7	150-184	6.9-8.0	6.8-7.5	15.7-15.9	4
May 20	4.0-13.0	140-187	7.5-9.0	6.6-7.6	15.7-15.9	26
April 22	4.0-10.0	140-180	6.7-8.7	6.6-7.4	13.0-14.0	14
September 13	7.5	120	6.0	6.1	13.0-14.0	3
October 23	5.0-10.0	89-164	5.5-9.6	5.2-7.1	13.0-14.0	15
October 25	6.0-10.0	94-134	4.5-7.1	5.2-6.6	13.0-14.0	9
June 5	2.5- 4.0	68- 73	3.9-6.5	4.6-4.7	6.9- 7.0	9
April 26	3.5- 4.5	75- 90	5.0-5.6	4.8-5.3	6.3	5
April 23	3.0	75	5.8	4.8	5.1- 5.7	3
June 4	3.0	50	4.0	3.9	5.1- 5.7	2
June 5	2.5- 3.5	50- 70	3.8-5.8	3.9-4.6	5.1- 5.7	10
April 23	2.5- 2.75	60- 70	5.4-6.2	4.3-4.6	4.0- 4.2	4
May 31	2.5	60	4.8	4.3	4.0- 4.2	2
May 31	2.0	45	4.9	3.7	3.3	4
June 3	2.5	50	4.8	3.9	3.3	3

Columns 1, 2, 3, 4, 6, and 7 were taken from Table X of Captain Gaillard's paper. Column 5 was calculated by Formula 2.

A study of the percentage of theoretical velocities in Table 4 shows that the smaller waves, containing less water, may travel with a smaller percentage before breaking.

The action of a deep-water wave passing into water of a gradually decreasing depth is as follows: As the wave enters shallow water, its

TABLE 4.—VELOCITY OF WAVES IN SHALLOW WATER IMMEDIATELY BEFORE BREAKING, NORTH BEACH, ST. AUGUSTINE, FLA., 1890-91.

Wave height.	Wave length.	Wave velocity, in feet per second:		Observed/Computed = Percentage of Theoretical.	Number of observations.
		Observed.	Computed. $V=1.804\sqrt{L}$		
(1)	(2)	(3)	(4)	(5)	(6)
Inches.	Feet.				
2	2.0	1.7	2.6	65	2
3	4.0	2.3	3.6	64	2
4	6.0	2.5	4.4	57	2
6	10.0	2.8	5.7	49	4
8	14.0	4.0	6.7	62	2
10	20.0	5.0	8.4	62	2
Feet.					
1.0	23.0	5.4	8.7	62	5
1.25	27.0	6.8	9.4	72	5
1.5	30.0	7.0	9.9	71	3
1.7	35.0	8.0	10.7	75	1
2.0	46.0	8.4	12.0	69	4
2.25	50.0	9.4	12.8	73	4
2.5	60.0	9.4	14.0	67	10
2.75	70.0	10.3	15.1	68	5
3.0	75.0	11.7	15.6	75	6
4.0	82.0	12.2	16.3	75	10
4.25	85.0	13.0	16.7	78	2
4.5	90.0	14.0	17.1	82	4
5.0	120.0	15.2	19.8	77	8
6.0	150.0	18.2	22.1	82	2
7.0	160.0	21.5	22.8	94	1

Columns 1, 2, 3, and 6 were taken from the table on pages 99 and 100 of Captain Gaillard's paper. Columns 4 and 5 were calculated by the writer. North Beach has a uniform slope of about 1:100. These observations were made during calm weather, or only when a moderate wind prevailed, with the idea of eliminating any possible effect of wind.

lower part, flowing over the bottom, is retarded by friction, and tends to delay the upper part. This reduction of velocity produces several other changes:

First.—Waves coming in from deep water must have the same period from crest to crest, and, as the velocity is reduced, the distance between the waves is shortened.

Second.—By Formula 2, the period is dependent on the length, and, as the period is the same, there will be a tendency to maintain the same length. While these two changes act against each other, it is probable that the lengths vary more directly with the first case, in the following proportion:

$$\frac{\text{Original velocity}}{\text{Original length}} :: \frac{\text{New velocity}}{\text{New length}} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

Third.—From Fig. 7 it is seen that the same quantity of water is carried along with the wave, and, if the wave length is shortened,

then the height will have to increase, in order to contain the same volume of water. There will be a little loss in the size of the wave, due to the friction.

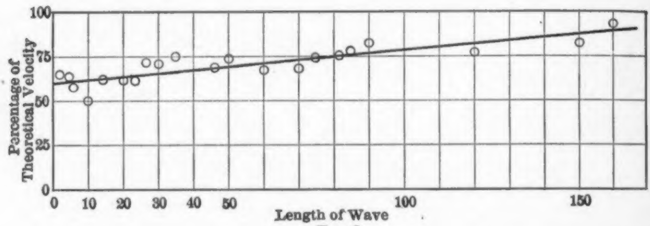

FIG. 9.

As the wave continues to advance, the velocity and length decrease, while the height increases. The friction on the bottom retards the motion of the lower layers, so that they are behind the upper layers in rotating, as is shown in Fig. 10. While the crest is moving forward, the lower layers are still moving forward and upward, so that the front of the wave is fairly steep, while the back is somewhat rounded. This action continues to increase until the crest becomes so unbalanced that it falls forward and breaks. The breaking of the wave is also assisted by the undertow, which reduces the available height of water and increases the friction of the lower part of the wave.

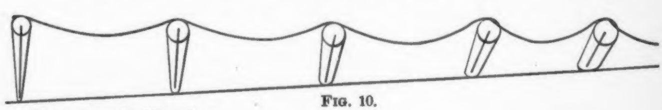

FIG. 10.

Captain Gaillard says:

"With a gentle slope of the bottom, or an opposed wind, [the height of the wave] was increased; while with a steeper slope, or with a wind in the direction of wave travel, [the height] was decreased."

This may be accounted for by the fact that with a gentle slope the wave has a chance to readjust itself to the new conditions and can become higher without breaking. The opposed wind has the effect of retarding the surface of the wave, thereby giving the lower layer a chance to keep up with the surface. With a steeper slope the wave does not have time to adjust itself, and therefore breaks. The wind traveling in the same direction partly causes the surface layers to move faster and partly blows the crest over.

Captain Gaillard makes the following statement:*

"Observations taken in the outer end of the Duluth Canal, August 9, 1901, when there was no current, showed that the maximum waves had a height of 12 feet. Similar observations at the same locality, taken half an hour later, when the velocity of the current opposed to the waves was about 2 feet per second, showed that the maximum waves were 14 feet high. The wind conditions were practically the same in both cases."

This may be explained as follows: These waves were formed in the lake, where there was no current; on approaching the entrance they met the current from the canal, and as the waves entered the canal the current was flowing out at about 2 ft. per sec. The waves were traveling at a certain velocity or period, and as they met the opposing current they still traveled at the same speed through the water; but, as the water was flowing to meet them, the waves gradually closed up until their length had been reduced by a number of feet equal to the product of the velocity of the flowing water and the wave period.

Formula 5 gives the approximate volume of water which is continually traveling forward with the wave, and, as the length is shortened, the height must be increased to contain the same volume of water.

In the observations under date of August 9th, 1901, in Captain Gaillard's Table X, the longest observed wave length and period will be examined, in order to see the result when moving into flowing water. The wave length is 130 ft., with a period of 6.8 sec., and the height will be considered as 12 ft. When this wave runs into an opposing current of 2 ft. per sec., the wave in rear will be nearer the wave in front by 6.8 times 2, or 13.6 ft., which reduces the length between crests to 116.4 ft.

By Formula 5, the volume of water moving forward with the wave in the lake will be approximately $\frac{130 \times 12}{4}$, while, with the wave traveling in flowing water there must be about the same volume, or $\frac{130 \times 12}{4} = \frac{116.4\,y}{4}$; in which y equals the required height, or 13.4 ft. As this calculation is only approximate, and the observations were taken half an hour apart, it cannot be expected that they will be exactly the same.

*On page 83 of his paper.

Waves running into a current flowing in the same direction would be reduced in height; while waves formed in flowing water and running into still water would have their height increased or decreased, according to whether the current was flowing with or against them.

The cause of the increase of the height of the wave is the same, whether the wave travels into water with a gradually decreasing depth, or if the bottom is level with converging sides. This action is also illustrated by the tidal wave in the Bay of Fundy and the British Channel.

Waves traveling through a narrow opening into a large bay or harbor are greatly reduced in height in the bay. This can be accounted for by the fact that a wave in the harbor cannot contain more water moving forward than the same wave had when passing through the opening.

The height of the wave in the harbor may in general be calculated by the inverse ratio of its length along the crest to the length when passing through the opening, as follows:

$$\frac{\text{Height in harbor}}{\text{Length on crest in opening}} :: \frac{\text{Height in opening}}{\text{Length on crest in harbor}} \dots\ (8)$$

Due allowance should be made for the shape of the harbor and causes tending to use up the force of the wave. The highest part of the crest will be in a line passing through the opening and extending in the direction of wave travel; while the crest on each side decreases with an increase of the

$$\frac{\text{Distance from the line of highest crest}}{\text{Distance of wave travel from the opening}}.$$

Force Exerted by Waves.

The forces exerted by waves may be classed as follows:

(*1st*) That due to the onward motion of the water in the wave; this may vary from zero to that caused by action similar to water hammer;

(*2d*) That due to static pressure caused by a column of water, or by turning the direction of the moving water upward;

(*3d*) That due to the receding of the wave; this may vary from zero to that caused by a column of water standing at a height equal to $\frac{v^2}{2g}$, in which v is the velocity of the wave and g is the acceleration due to gravity;

(*4th*) That caused by floating objects on the water, as cakes of ice or logs, which may be hurled by the waves against any barrier.

1st. Force Due to Onward Motion of the Water.—It is probable that the full force of water hammer is never realized, and the nearest approach to such action would be when the water may rush into some opening in a wall or other structure which has an opening large enough to permit the air to escape, but is not large enough to take care of much water. If there is no escape for the air, it will be compressed until such time as the flow of the water is stopped and recedes to its normal state.

When the water is confined and there is a sudden stoppage of the flowing water, it exerts a pressure in all directions; but when the water is free, as in a wave, the force is nearly all in the direction in which the water is moving. This direction of water travel is the most important consideration of the forces in the wave.

In the case of a pile placed by itself in water, the force of a wave acting against it at any depth would be that caused by the velocity of the water, and would depend on the shape of the pile in allowing the water to flow past it. This same condition would hold true for the ends of a pier or other structure not broad enough to make a complete stop to the wave. In the case of a wall or breakwater which completely stops the passage of the wave, entirely different conditions obtain.

Fig. 11 represents a wall, *ABCD,* with a vertical face, the depth in front of the wall being such that the wave does not break. The distance, *KL,* is the height of the waves as they approach the wall, while *EF* represents the limits of the highest and lowest parts of the surface of the wave against the wall, and may be twice as much as *KL.*

It can be seen from the figure that the wall below *F* is always submerged, so that the water cannot be moving in a direction against the wall, and there will never be any force of a kinetic nature directly against it below this point.

The rise of the water against the wall, from *F* to *H,* is mostly by displacement, and, being in a vertical direction, the wave exerts hardly any force against the wall between these limits.

From *H* toward *E* there begins to be some horizontal motion against the wall, and this increases in force until the maximum is reached, at which point there is the greatest horizontal motion, together with a

sufficient quantity of water, and from there to the top of the wave the force decreases as the quantity of water becomes less.

In deep water there will not be a very high force against a wall of this form, as the water next to it, in moving upward, deflects somewhat that which is moving horizontally.

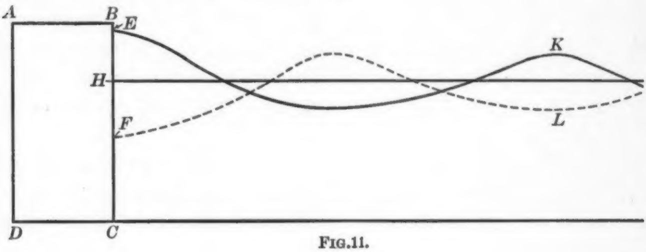

FIG. 11.

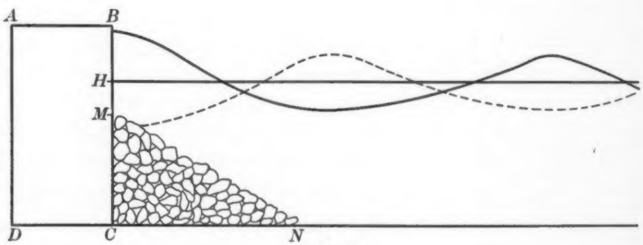

FIG. 12.

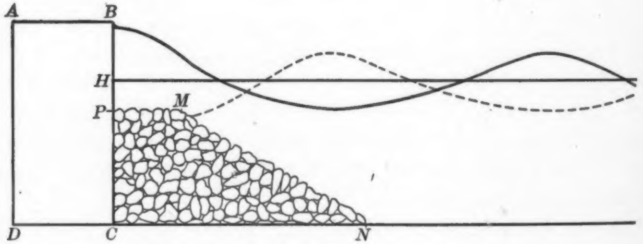

FIG. 13.

Fig. 12 shows the same wall, but with a slope of rip-rap in front of it, as shown by *MNC*.

Formula 5 gives the approximate quantity of water moving forward with the wave, and in Fig. 11 this moving water is distributed down

to the bottom and travels nearly up to the wall, where the force is lost by raising the water above its normal level.

In Fig. 12 the same quantity of water is traveling forward with the wave; but, on reaching the top of the rip-rap, the vertical height through which the wave passes is reduced, and, as it nears the wall, the moving water is concentrated into a comparatively small depth, and rushes forward and a little upward with great force against the face of the wall.

In Fig. 13 are shown the same conditions as in Fig. 12, but with a berm, *MP*. In this case, as the wave reaches the top of the slope, it looses its upward motion, and rushing forward strikes the wall square on the face.

In general, when the water in motion is concentrated into a small space, the force is also concentrated and the wave strikes with much greater power. When the face of the wall is perpendicular to the direction of water travel, it has to withstand a great force, but the reduction of the wave will be greater. When the wall is at an angle to the direction of water travel, it does not have to stand as much force, for the wave is partly deflected, to be broken up farther on.

In Figs. 12 and 13 the wave will break while on the rip-rap, causing the water to rush forward with great force.

The wave, breaking just before it reaches the wall, exerts the greatest force against it, consisting of the wave striking the wall and of changing the direction of the moving water from a horizontal to an upward one. When the wave breaks on the beach, there is the same horizontal action as in the previous case, but the water is allowed to travel onward, and spends its force on the beach.

2d. Force Due to Static Pressure.—First, there is the pressure due to the height of the water, and, second, the pressure caused by deflecting the water upward. The most important static pressure is that caused by deflecting the moving water. As the water, in moving forward horizontally, strikes the wall, its motion is not stopped, but continues in any direction that it may go. When the wave strikes the wall, it tries to go in all directions parallel to its face, and so exerts a pressure downward and against the wall. This pressure must be sufficient to cause the water to move upward, as this is the only direction in which it can go.

These two forces, kinetic and static, give pressures independent of

each other, but are united into a greater pressure wherever they act at the same place.

The first, or kinetic pressure, may be found with a spring dynamometer, while the total pressure at any point of both the kinetic and static forces may be found with a diaphragm dynamometer. For the purpose of illustrating the pressure registered by these two types, Table 5 from Table XVIII, and Table 6 from Table XXI, of Captain Gaillard's paper are here given.

TABLE 5.—OBSERVATIONS WITH SPRING DYNAMOMETERS ON LAKE SUPERIOR, 1901-1903; OUTER END OF SOUTH PIERS, DULUTH CANAL AND SUPERIOR ENTRY.

Date.	Stage of lake above low-water datum, in feet.	OBSERVED MAXIMUM WAVE DIMENSIONS:			CORRESPONDING MAXIMUM DYNAMOMETER READINGS. PRESSURE, IN POUNDS PER SQUARE FOOT:			
		Height, in feet.	Length, in feet.	Velocity, in feet per second.	End of south pier, Duluth Canal. Elevation above low-water datum at which dynamometers were set:			South pier, Superior Entry.
					"C" +0.07 ft.	"F" +3.74 ft.	"A" +7.01 ft.	"E" +3.74 ft.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1901.								
July 24th........	+1.7	12	150	24.2	250	1 150	1 030	Not set.
August 9th......	+1.9	12	130	24.2	370	1 075	780	1 190
September 24th..	+1.9	16	250	33.2	1 630	1 930	2 050	2 255
								"D"
October 9th	+1.7	10	150	23.7	000	000	500	1 210
November 6th...	+1.9	13	150	29.6	000	1 275	1 260	1 615
November 22d...	+1.4	14	150	27.2	000	1 010	1 605	1 605
					"C"	"E"	"G"	
1902.					+7.04 ft.	+12.57 ft.	+16.18 ft.	Removed.
October 23d	+1.5	13	200	30.0	800	445	000	Removed.
October 25th	+1.7	16	200	30.0	1 755	1 335	000	Removed.
November 12th..	+1.7	18	250	32.0	2 370	2 195	1 370	Removed.
December 20th..	+1.7	16	210	31.0	1 700	1 430	515	Removed.

It will be seen that the spring dynamometer, "C," when set from 1.3 to 1.8 ft. below the general level of the water, gave readings only on 3 out of 6 days, and registered the kinetic energy of the wave; while the diaphragm dynamometer, No. 2, when set from 0.6 to 1.1 ft. below the general level of the water, gave many readings on each day, while the observations were being taken, and registered the total force of the wave against the dynamometer.

TABLE 6.—OBSERVATIONS WITH DIAPHRAGM DYNAMOMETERS AT OUTER END OF SOUTH PIER, DULUTH SHIP CANAL.

Date.		Stage of water above low-water datum, in feet.	Period occupied in observing, in minutes.	Maximum corresponding wave dimensions: Height in feet.	Length, in feet.	Velocity, in feet per second.	Principal synchronous dynamometer readings. Pressure, in pounds per square foot. Dyn. 2.	Dyn. 1.	Total number of readings recorded.
(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1902.									
June	17........	+1.2	25	4.8	50	16.0	410	000	26
"	17........	....	..	....	...	....	385	000	...
July	2........	+1.3	38	5.0	50	16.0	531	000	16
"	2........	....	..	....	...	....	485	000	...
"	3........	+1.2	62	5.0	70	19.0	677	000	30
"	3........	....	..	....	...	....	677	000	...
August	18........	+1.6	91	6.0	90	21.3	864	....	79
"	18........	....	..	....	...	....	864	000	...
"	18........	....	..	....	...	....	792	50	...
"	18........	....	..	....	...	....	720	....	...
"	18........	....	..	....	...	....	720	110	...
"	18........	....	..	....	...	....	648	000	...
"	18........	....	..	....	...	....	331	166	...
"	18........	....	..	....	...	....	315	166	...
"	18........	....	..	....	...	....	364	149	...
October	23........	+1.5	81	10.0	150	25.0	965	....	292
"	23........	....	..	....	...	....	821	....	...
"	23........	....	..	....	...	....	821	202	...
"	23........	....	..	....	...	....	821	000	...
"	23........	....	..	....	...	....	821	58	...
"	23........	....	..	....	...	....	677	101	...
"	23........	....	..	....	...	....	677	58	...
"	23........	....	..	....	...	....	677	22	...
"	23........	....	..	....	...	....	677	130	...
"	23........	....	..	....	...	....	461	1 210	...
"	23........	....	..	....	...	....	461	778	...
"	25........	+1.7	63	13.0	200	30.0	965	230	118
"	25........	....	..	....	...	....	965	000	...
"	25........	....	..	....	...	....	821	144	...
"	25........	....	..	....	...	....	677	(a)	...
"	25........	....	..	....	...	....	677	302	...
"	25........	....	..	....	...	....	677	230	...
"	25........	....	..	....	...	....	677	000	...
"	25........	....	..	....	...	....	504	634	...
"	25........	....	..	....	...	....	389	634	...
"	25........	....	..	....	...	....	353	(a)	...
"	25........	....	..	....	...	....	317	(a)	...
"	25........	....	..	....	...	....	....	1 642	...
"	25........	....	..	....	...	....	....	634	...
Total........		......	360	......	......	......	......	......	561

(a) The movement of the index hand of the gauge was so rapid for these three observations that the observer could not follow it with his eye quickly enough to secure accurate readings, but was of the impression that in each of these cases it corresponded to as much as 20 lb. per sq. in., or, after correction for index error, 2 794 lb. per sq. ft. He was of the impression that the movement of the index hand in these cases was so rapid that it probably passed beyond its true position. For these reasons, and until further experiments can be made to determine this point, it has been considered best not to include them in the preceding table.

The formula commonly used for calculations of the theoretical force of flowing water against a plate which is set in the current and normal to it, is:

$$P = f \frac{w}{2g} A v^2$$

In which P denotes the pressure, in pounds;

f = a coefficient to be determined;

w = the weight of a cubic foot of water, in pounds;

g = the acceleration due to gravity, in feet per second;

v = the velocity of the current, in feet per second; and

A = the area of the plate, in square feet.

Captain Gaillard has used $(v + v'')^2$ in place of v^2, in which v equals the velocity of the wave and v'' the velocity of the particles of water in their orbits, and he has determined a constant from the results of his tests to be used as f.

While the writer agrees that the velocity of the wave should be used and that the velocity may be increased by v'', he also thinks that the velocity may be much greater than $v + v''$, and that the static pressure should be considered, therefore he prefers to use only the velocity of the wave and to have a varying coefficient, as f, to suit the conditions.

Tables 7, 8, 9, and 10 are here given, and an effort will be made to show why the Formula, $P = f \frac{w}{2\,g} A\, v^2$, is used.

Columns 1, 2, 3, 4, 5, 6, 8, 9, and 11 of Tables 7 and 8 are taken from Table XXII, Sections I and II, of Captain Gaillard's paper. Column 9 is found by the formula, $P = f \frac{w}{2\,g} A\,(v + v'')^2$, and using the average of Column 6, or 1.31, for the value of f. Columns 7 and 10 were calculated by the writer, and substituting in Table 7 the mean value of f, or 2.32, in the 7th column, for the coefficient in the 10th column. In Table 8 the coefficient for use in the 10th column was determined by using the mean of f, or 2.00, as found in the 7th column of this table and of Table 9.

Table 10 is from Captain Gaillard's Table XIX. The observations of Table 7 were taken on the beach, and the dynamometers were placed in position so that the wave had broken before reaching them. The observations of Tables 8 and 9 were taken from the same place, on the outer end of the south pier, Duluth Canal, the water being about 24 ft. deep in front of the pier.

A study of these tables will show that when the waves break on the beach, the water being contracted into a lesser depth, the coefficient

is 2.32. At the outer end of the south pier, with 24 ft. of water, it is probable that the wave does not have a chance to break with as much force in comparison to its size as when on the beach, because of the depth and the distribution of the moving water down to the bottom. The average coefficient in this case is 2.00. Substituting $(v + v'')^2$ for v^2 in these two cases gives for the coefficients values of 1.32 and 1.21, respectively, which shows there must be a difference in the conditions.

In both of these cases the wave was not completely stopped, but flowed around the dynamometer and kept on its way. When a wave strikes a wall, its progress is stopped, and there will be a force against the wall caused by both the stopping and turning upward of the moving water.

TABLE 7.—COMPARISON OF OBSERVED AND COMPUTED MAXIMUM READINGS OF SPRING DYNAMOMETERS.

North Beach, St. Augustine, Fla., 1890-91.

MAXIMUM WAVE DIMENSIONS:			v'' (computed) in feet per second.	$(v + v'')^2$	$f = \frac{2gP}{w(v+v'')^2}$	$f' = \frac{2gP}{wv^2}$	MAXIMUM DYNAMOMETER READINGS. PRESSURE, IN POUNDS PER SQUARE FOOT.			Number of observations.
Height, in feet.	Length, in feet.	Velocity, in feet per second.					Observed, in pounds.	Computed, $P = 1.31 \frac{w}{2g} A (v + v'')^2$ in pounds.	Computed, $P = 2.32 \frac{w}{2g} v^2$ in pounds.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
2.0	46	8.4	2.9	127.7	1.16	2.08	148	168	160	1
2.5	60	9.4	3.2	158.8	1.45	2.61	230	209	191	12
2.75	70	10.3	3.5	190.4	1.41	2.51	269	249	240	5
3.0	75	11.7	3.7	237.2	1.36	2.35	322	310	310	20
3.5	78	12.0	4.0	256.0	1.22	2.17	313	335	325	8
4.0	82	12.2	4.1	265.7	1.53	2.55	406	348	359	20
4.5	90	14.0	4.9	357.2	1.27	2.31	452	469	443	15
5.0	120	15.2	5.3	420.2	1.11	2.02	467	550	522	16
5.5	130	16.7	5.7	501.8	1.10	1.97	550	657	631	3
6.0	150	18.2	6.2	595.4	1.12	2.01	667	780	748	7
Total.	....	....	....	......	....	....	....	....	....	107
Mean.	....	....	....	......	1.32	2.32	....	....	....	....

TABLE 8.—COMPARISON OF OBSERVED AND COMPUTED MAXIMUM READINGS OF SPRING DYNAMOMETERS.

Duluth Canal and Superior Entry, Lake Superior, 1901-02.

MAXIMUM WAVE DIMENSIONS:							MAXIMUM DYNAMOMETER READINGS. PRESSURE, IN POUNDS PER SQUARE FOOT.			
Height, in feet.	Length, in feet.	Velocity, in feet per second.	v'' (computed), in feet per second.	$(v+v'')^2$	$f = \frac{2gP}{(v+v'')^2}$	$f' = \frac{2gP}{wv^2}$	Observed, in pounds.	Computed, $P = 1.31 \frac{w}{2g} A (v+v'')^2$ in pounds.	Computed, $P = 2.00 \frac{w}{2g} A v^2$ in pounds.	Number of observations.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
12.0	150	24.2	7.3	992.2	1.20	2.02	1 150	1 259	1 138	1
12.0	130	24.2	7.9	1 030.4	1.20	2.09	1 190	1 307	1 138	1
16.0	250	33.2	10.6	1 918.4	1.22	2.11	2 255	2 432	2 138	1
10.0	150	23.7	6.0	882.1	1.41	2.22	1 210	1 118	1 090	1
13.0	150	29.6	9.8	1 552.4	1.07	1.90	1 615	1 968	1 700	1
14.0	150	27.2	9.6	1 354.2	1.23	2.24	1 605	1 718	1 434	1
16.0	200	30.0	10.3	1 624.1	1.12	2.01	1 755	2 059	1 746	1
18.0	250	32.0	11.5	1 892.2	1.29	2.39	2 370	2 400	1 986	1
16.0	210	31.0	10.4	1 714.0	1.02	1.83	1 700	2 174	1 862	1
Total..	....	....	....	......	....	....	....	......	......	9
Mean..	....	....	....	......	1.20	2.09	....	......	......	..

The following is quoted from Captain Gaillard's paper,* and followed his Table XIX:

"It will be noticed that dynamometer *M*, measuring the vertical force, gave a reading for every storm, while *O* gave no reading whatever for 5 out of 10 storms. The largest single reading was due to vertical force, which was in excess of the horizontal in 6 out of 8 cases.

"It is to be regretted that it was not practicable to set the pressure plate of dynamometer *O* flush with the face of the sea wall. If this could have been done the results might have been different, for on several occasions masses of water were seen projected rapidly upward along the face of the sea wall, the layer of water apparently being not more than a foot or so in thickness measured perpendicularly to the wall. This mass of water would impinge upon the pressure plate of dynamometer *M*, squarely and with considerable force, but would apparently produce no effect on dynamometer *O*. It is quite possible that the effect of the vertical wall, only a foot in rear of the pressure

* Page 159.

plate of dynamometer *O*, might have been to cause a counter pressure on the rear of this plate so soon after wave impact against the front, that during some storms no compression could take place. For this reason the types of spring dynamometers heretofore used do not appear well adapted for use against an area of large extent, and of a form which tends to prevent water in rear of the pressure plate from moving freely away.

"It would seem from what has been stated, that they may, as a result of counter pressure, give readings too *small*, but cannot give readings too *large*.

"The effect of this sea wall was to produce concentrated wave energy at times, and this could plainly be seen in the case of the upward vertical force.

"It is further shown by the fact that although the water just in front of the wall was never deeper than 5.2 feet, yet three dynamometer readings were obtained which were greater than the maximum reading at either the south pier of the Duluth Canal or at Superior Entry, and are on an average about four times greater than the maximum dynamometer reading for breaking waves of equal size at North Beach, Florida."

TABLE 9.—COMPARISON OF OBSERVED AND COMPUTED MAXIMUM READINGS OF DIAPHRAGM DYNAMOMETERS ON OUTER END OF SOUTH PIER, DULUTH CANAL, 1902.

MAXIMUM WAVE DIMENSIONS:							MAXIMUM DYNAMOMETER READINGS. PRESSURE PER SQUARE FOOT.		
Height, in feet.	Length, in feet.	Velocity, in feet per second.	v'' (computed), in feet per second.	$(v+v'')^2$	$f = \frac{2gP}{w(v+v'')^2}$	$f' = \frac{2gP}{wv^2}$	Observed, in pounds.	Computed, $P = 1.31 \frac{w}{2g} A (v+v'')^2$ in pounds.	Computed, $P = 2.00 \frac{w}{2g} A v^2$ in pounds.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
4.8	50	16.0	4.7	428.5	0.99	1.65	410	542	496
5.0	50	16.0	4.9	436.8	1.26	2.14	531	553	496
5.0	70	19.0	4.2	538.2	1.30	1.93	677	681	700
6.0	90	21.3	4.6	670.8	1.33	1.96	864	850	880
10.0	150	25.0	6.3	979.7	1.28	2.00	1 210	1 241	1 204
13.0	200	30.0	8.5	1 482.2	1.14	1.86	1 642	1 877	1 743
Mean..	....	....	....	....	1.22	1.92	....	....	....

Columns 1, 2, 3, 4, 5, 6, 8, and 9 were taken from the Table XXIII of Captain Gaillard's paper. Column 9 was computed in the same manner as Column 9 of the two previous tables. Columns 7 and 10 were calculated by the writer, the last being found as was Column 10 of Table 8.

From these tables and the remarks it can be seen that the value of the coefficient, *f*, will vary according to the conditions under which the wave is stopped.

TABLE 10.—OBSERVATIONS WITH SPRING DYNAMOMETERS FASTENED TO SEA WALL, SOUTH OF SOUTH PIER, DULUTH CANAL, LAKE SUPERIOR.

Dynamometer *"O,"* face vertical.

Dynamometer *"M,"* face horizontal.

Date.	Stage of lake above low-water datum, in feet.	Depth at dynamometers on date given, in feet.	Corresponding depths 200 ft. lakeward, in feet, "O."	MAXIMUM DYNAMOMETER READINGS. PRESSURE, IN POUNDS PER SQUARE FOOT:	
				"O" Elevation = +4.00 ft.	"M" Elevation = +3.70 ft.
(1)	(2)	(3)	(4)	(5)	(6)
1902.					
August 18	+1.6	5.1	6.6	1 100	Not set.
September 15	+1.3	4.8	6.3	000	610
" 20	+1.2	4.7	6.2	000	690
October 13	+1.0	4.5	6.0	000	655
" 16	+1.2	4.7	6.2	000	770
" 23	+1.5	5.0	6.5	2 430	2 725
" 25	+1.7	5.2	6.7	000	1 100
November 12	+1.7	5.2	6.2	1 160	790
December 6	+1.3	4.8	6.3	1 060	Not read.
" 20	+1.7	5.2	6.7	2 490	1 100

3d. Force Due to the Receding of the Wave.—In Fig. 7 it was shown that the same volume of water is carried forward with the wave and also backward in the trough.

A pile placed by itself in water will be subject to pressure from the forward movement of the wave and also the backward movement in the trough. These pressures will be nearly the same, except that one will be applied lower than the other.

If a pipe, 10 ft. high and having an area of 1 sq. ft., were closed at the lower end and filled with water, the pressure on the bottom would be about 625 lb. Then if the upper end were closed and the lower end released so that the water would be held up by the top end, the water would be exerting a pull downward of about 625 lb. If there was a sufficient supply of water, so that there would always be a head of 10 ft. on the lower end when both ends were open, and the lower end were closed with a plug having an area of 1 sq. ft., it would

probably take a much greater pressure than 625 lb. to stop the flow. These conditions are similar to those in a sea wall which is exposed to wave action.

When the wave in its forward motion strikes the wall, there will be a force in excess of a pressure caused by a column of water of sufficient height to produce the velocity of the wave.

When the wave is receding, there is no horizontal motion next to the wall; but, if the wall were not there, the water would move with a velocity suitable to the conditions, and thus the wall holds the water from moving like the closed upper end of the pipe.

This suction or pull on the wall would be nearly equal to the weight of a column of water of a height sufficient to produce the velocity of the moving water. This pull would not be equal to the theoretical amount, because, as the water cannot move directly from the wall, the general level of the water is lowered to make up the deficiency.

From Fig. 11 it can be seen that as the water is descending from *B* to *H* there will not be any pull on the wall on account of it being higher than the adjacent water. As the water drops below *H,* it begins to pull on the wall, and probably reaches the maximum about half way from *H* to *F,* and then the pull decreases until the water reaches the lowest point, when it begins to rise again.

The best conditions occur when the wall is tight, so that no water can pass through; but if the wall is porous, as a rock-filled crib would be, then, in addition to the force already described, there would be forces caused by the pressure of water on the inside and the friction of the water moving through the crib.

If there is a slope of rip-rap in front of the wall, as in Fig. 12, then the receding water, being contracted into a much smaller space, will flow with a much greater velocity, and is likely to take some of the rip-rap along with it.

AMERICAN SOCIETY OF CIVIL ENGINEERS
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TRANSACTIONS

Paper No. 1187

HYDROMETRY AS AN AID TO THE SUCCESSFUL OPERATION OF AN IRRIGATION SYSTEM.*

BY J. C. STEVENS, ASSOC. M. AM. SOC. C. E.

WITH DISCUSSION BY MESSRS. E. F. CHANDLER, C. E. SHIPMAN, CLEMENS HERSCHEL, ROBERT FOLLANSBEE, AND J. C. STEVENS.

The successful operation of a large irrigation project is a task that requires both engineering skill and business ability. The tendency toward larger projects is an inevitable one in the West; some of them now cover 300 sq. miles of territory, and include several goodly-sized cities within their boundaries.

Within these communities the highest type of agricultural development is to be found. Small holdings and intensive cultivation is the keynote of success, both from the standpoint of the management and of the agriculturist.

The time is not far off when the water used on these large systems will be distributed as carefully as under the metered systems of large cities, where patrons pay only for the water they use. In the absence, however, of a simple device for measuring the total quantity, the present method of delivering water at a continuous rate is the most practicable. Contracts for water usually specify a certain rate of flow per acre of land irrigated. This method is ineffectual, for obvious reasons, and becomes less effective as the size of the farm unit becomes smaller, but it is adopted because it simplifies operation. A simple

* Presented at the meeting of December 7th, 1910.

and inexpensive device to measure the total quantity flowing in an open channel as effectively as a meter measures that flowing in a pipe, is a great need, for such a device, if in general use, would overcome a hundred difficulties which are now almost insurmountable. On many projects, the practice of rotation is followed with excellent results, but the rate-measurement is still necessary.

Except in the larger canals and laterals, it is not likely that any device can supersede weirs; but in many such channels there is not sufficient fall to permit their use. The only other method available is that of the current meter.

During the seasons of 1908 and 1909 the writer made a hydrometric study of the Sunnyside Project of the United States Reclamation Service in Washington. The work in 1908 included seepage investigations on certain laterals of the system selected for that purpose; and in 1909 a similar study of the entire system was instituted, with plans for its continuance as an operation adjunct. As this work involved some interesting features of water measurement by current meter and weirs, a discussion of hydrometric work as conducted on that project will doubtless be of interest to engineers engaged in irrigation practice.

General Description of the Sunnyside Project.

The Sunnyside Canal diverts water from the left bank of the Yakima River, in Sec. 28, T. 12 N., R. 19 E., Willamette Meridian. The canal system was purchased from the Washington Irrigation Company by the United States Reclamation Service in 1906. It then irrigated about 40 000 acres of land, and the plans of the Reclamation Service are for its ultimate enlargement to cover 90 000 acres. Active operation by the Government began in 1907.

The canal is now 60 miles in length, and parallels the Yakima River in its general direction. It irrigates practically all the land between the canal and the river, and has one lateral—Mabton Siphon—which crosses the river to lands on the south side. In all, about 47 000 acres of land were irrigated in 1909.

The soil of the valley is of volcanic ash, loam, sand, and clay, with occasional deposits of gravel. Near the lower extremity of the canal, lava rock is found, porous in texture, with occasional pockets or large voids.

Sandy volcanic ash makes an exceedingly productive soil, and some of the crop values reported are almost beyond belief. The better fruit lands lie along the upper portions of the canal and at the higher elevations in the lower portions. Diversified farming is the rule, and small holdings of from 10 to 40 acres predominate. In the favorable sections fruit is the leading crop, and in other parts large quantities of alfalfa are grown. The lands above the canal are covered with sage-brush, and their desert-like appearance presents a striking contrast to the well-kept orchards and green alfalfa fields below it.

The rainfall averages 7 in. per annum, a large portion of which occurs as snowfall during the winter.

The Operation Department is concerned with the distribution of the water, the maintenance of the system, the collection of rentals and fees, and the returning to the Reclamation fund of the cost of construction. For ease of operation, the main canal and the principal laterals are divided into beats. Each beat is in charge of a patrolman whose duty it is to inspect daily the condition of his portion of the main canal, to regulate the head-gates for the diversion of the water from the main canal to the laterals, and for the delivery of water to individual tracts.

Mile-posts have been placed throughout the entire length of the main arteries, and place-designations are made by numbers corresponding to their distance in miles from the intake. At convenient points telephone booths have been erected, and the entire system is connected by telephone with the manager's office.

Gauging stations are established at the extremities of each beat, where the discharge is measured. At all points of diversion from the main arteries, there are weirs or other measuring devices in the laterals, with gauges to indicate the head of water. Readings of gauge heights at gauging stations, and of the head of water on weirs in diverting laterals, are made each morning by the patrolmen, who report them by telephone to the manager's office, where a receiving clerk records them on suitable forms. The patrolman's report card is forwarded to the office after the Saturday report, where the reports received by telephone are checked against the original records.

The collecting of these records is in charge of a field engineer or hydrographer, who also makes the necessary current-meter measurements, and computes and analyzes the data as they accrue. He also

makes daily, weekly, and monthly reports to the manager, showing the quantity of water received at the intake, the quantity diverted into laterals for irrigation, and the quantity wasted and lost. These reports are used by the manager and superintendent for regulating the water throughout the entire system, in order to meet the ever-changing requirements.

In 1909 the division of the canal system into beats was made without consulting the Hydrometric Division, since operation requirements governed the selection, rather than ease of determining flow. The hydrographer, therefore, was required to determine discharges at certain designated points without regard to obstructions or poor gauging conditions which might be encountered.

Table 1 gives the subdivisions for 1909, and the manner in which the stations are designated. For convenience, the gauging stations are given names corresponding to the nearest even mile number. The number and kind of measuring devices at the head of diverting laterals is also given.

TABLE 1.—SUBDIVISIONS OF SUNNYSIDE CANAL SYSTEM, FOR OPERATION REQUIREMENTS, IN 1909.

Number of beat.	Extends:		Number and kind of diversions.
	From:	To:	
	MAIN CANAL.		
1	Intake	8.03-Mile	28 " Konnewocks."*
2	8.03-Mile	17.00-Mile	19 " Konnewocks."* 27 1-ft. Weirs. 6 2-ft. Weirs. 2 3-ft. Weirs. Zillah Waste-way.
3	17.00-Mile	22.90-Mile	12 1-ft. Weirs. 3 2-ft. Weirs. 8 3-ft. Weirs. 1 6-ft. Weir.
4	22.90-Mile	27.60-Mile	5 1-ft. Weirs. 3 2 ft. Weirs. 2 3-ft. Weirs. 1 5-ft. Weir. 1 6-ft. Weir.
5	27.60-Mile	30.34-Mile	6 1-ft. Weirs. 6 2-ft. Weirs. 3 3-ft. Weirs. 2 4-ft. Weirs. 2 5-ft. Weirs. 2 6-ft. Weirs.
6	30.34-Mile	32.27-Mile	4 1-ft. Weirs. 1 2-ft. Weir. 3 3-ft. Weirs. Snipe's Mountain Lateral.

* A description of " Konnewocks " is given on p. 319.

TABLE 1.—(*Continued.*)

Number of beat.	Extends:		Number and kind of diversions:
	From:	To:	
Snipe's Mountain Lateral.			
S — 1	Intake	6-Mile	16 1-ft. Weirs. 4 2-ft. Weirs. 1 3-ft. Weir. Turner Lateral.
S — 2	6-Mile	9-Mile	14 1-ft. Weirs. 4 2-ft. Weirs. 1 5-ft. Weir. 1 8-ft. Weir.
Rocky Ford Lateral.			
R — 1	Intake	3-Mile	4 1-ft. Weirs. 1 2-ft. Weir. 1 8-ft. Weir.
Main Canal.			
7	32.27-Mile	37.77-Mile	2 1-ft. Weirs. 11 2-ft. Weirs. 3 3-ft. Weirs. 1 4-ft. Weir. 1 6-ft. Weir. 2 1-ft. Weirs.
8	37.77-Mile	42.63-Mile	4 1-ft. Weirs. 10 2-ft. Weirs. 3 4-ft. Weirs. 1 5-ft. Weir.
9	42.63-Mile	48.31-Mile	2 1-ft. Weirs. 8 2-ft. Weirs. 2 3-ft. Weirs. 1 6-ft. Weir. 1 12-ft. Weir.
10	48.31-Mile	52.05-Mile	3 1-ft. Weirs. 5 2-ft. Weirs. 3 4-ft. Weirs. 1 6-ft. Weir. 1 12-ft. Weir. Mathieson Lateral.
11	52.05-Mile	55.73-Mile	6 1-ft. Weirs. 2 2-ft. Weirs. 1 4-ft. Weir. 2 6-ft. Weirs.
12	55.73-Mile	59.47-Mile	4 1-ft. Weirs. 3 2-ft. Weirs. 1 3-ft. Weir. 2 4-ft. Weirs. 1 6-ft. Weir.

Between the intake and the 17-Mile station on the main canal there are a great many miner's-inch modules. All deliveries in Beat 1 and about half the deliveries in Beat 2 are provided with these modules. They consist of an elongated orifice, 2 in. high, with a slide

PLATE XXXIX.
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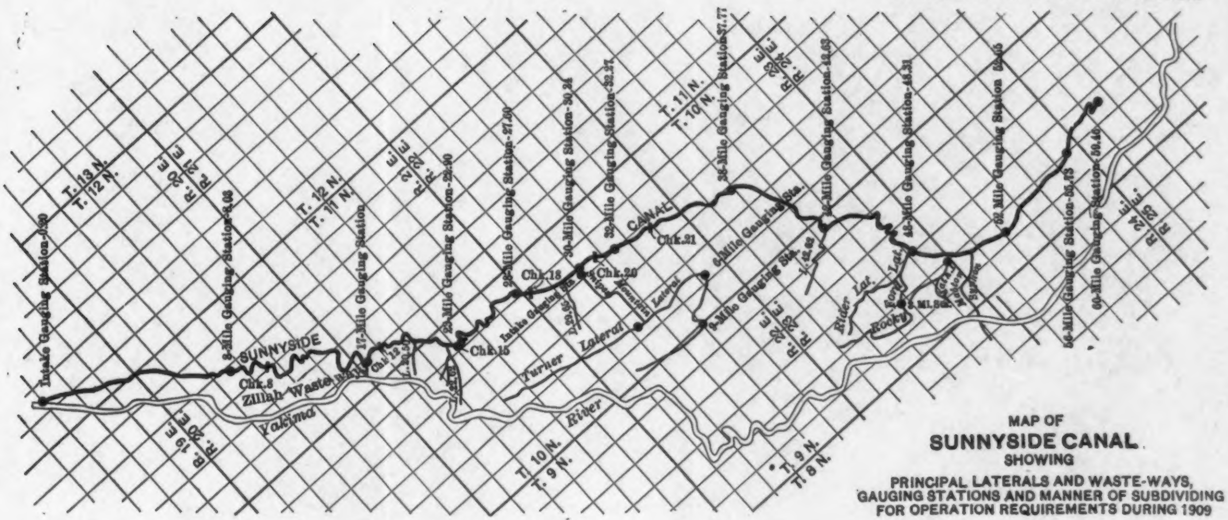
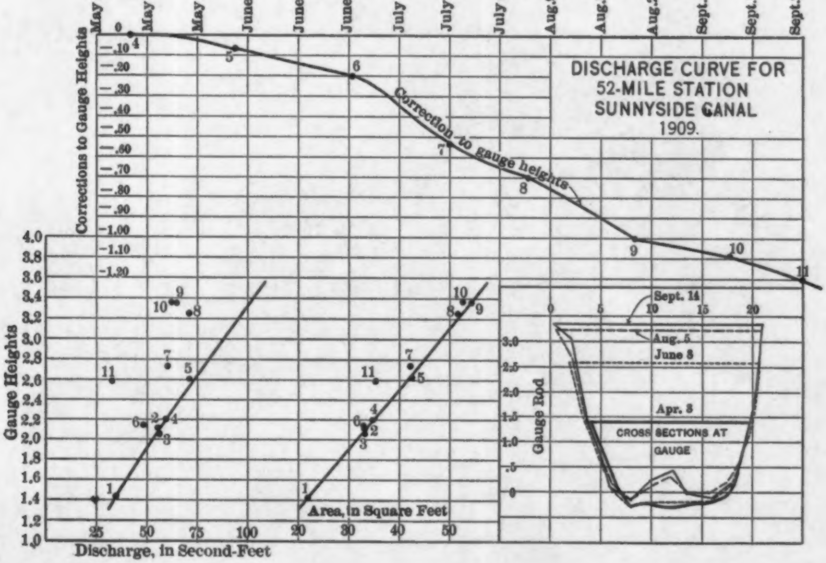


MAP OF
SUNNYSIDE CANAL
SHOWING
PRINCIPAL LATERALS AND WASTE-WAYS,
GAUGING STATIONS AND MANNER OF SUBDIVIDING
FOR OPERATION REQUIREMENTS DURING 1909



by which the length of the orifice can be varied. There is a long spillway which purports to keep the water at a head of 6 in. over the top of the orifice. They are crude structures, and are very indifferent measuring devices, but their use is required by the terms of a contract with the old Konnewock Irrigation Company which installed them. From this fact they are called "Konnewocks."

Trapezoidal weirs are maintained at other delivery points. They consist essentially of a weir board cut to the proper form and covered with a ready-made strip of galvanized iron bent and soldered to shape.*

On Plate XXXIX there is a condensed map of the entire canal system showing the manner in which it is subdivided and the location of all gauging stations maintained during the season of 1909.

Canal Hydrometry.

The desire for greater efficiency in operation led to the adoption of a hydrometric division as a part of the Operation Department of the Sunnyside Project. It was soon realized that conservative distribution could not be obtained without a systematic and exhaustive study of the disposition of all waters diverted into the canal, the object being to determine as nearly as possible the relative quantities actually used on agricultural lands, wasted in operation, and lost by seepage and evaporation.

The first steps were necessarily experimental, for the scheme opened up somewhat new phases of hydrometric work. The chief difference consists in the fact that a much higher degree of accuracy is required than is considered necessary in ordinary river hydrometry. The truth of this will be at once recognized after considering the ultimate aim of the two lines of work.

In river hydrometry the aim is to determine the flow at desired points in order that the future behavior of streams may be predicted, the assumption being that past behavior is a fair indication of future conditions.

These data form a basis for the design of structures, and for determining the feasibility of proposed projects. In general, if results on rivers are secured within 10% of the actual flows they are sufficiently accurate for practical purposes, for it would not be wise to go

* A description and calibration of the Sunnyside type of weir may be found in *Engineering News*, August 18th, 1910.

to the expense of securing ultra-refined results on rivers when it is known that past behaviors are only approximate indications of the future. Other uses for river data, of course, create exceptions to this general statement.

In canal hydrometry, however, an entirely different perspective must be taken. The flow is always under artificial regulation. Unnecessary wastes are at once detected, and changes for betterment, either in structures or methods of delivery, can be adopted, with actual data as a basis. The diversion of more water than is required for the system unnecessarily deprives other canals, below or above, of water that could be used beneficially elsewhere. From the operation standpoint, in connection with the "human problems" encountered, it is highly important to know at all times how much water is being delivered to every farm unit of the system. In short, if systematic hydrometric work is carried on, in conjunction with the operation of any canal system, the officers know the conditions at all times; if not, they work blindly.

A little reflection will reveal the exacting nature of these investigations, if consistent results are obtained. The hydrometric division is frequently concerned with differences of 1 sec-ft. or less in 500 or more. It is impossible, of course, to secure as accurate results as this, yet they are useless unless they possess a degree of accuracy considerably beyond that heretofore conceded possible in ordinary field hydrometry. The present methods cannot be discarded, but they can be refined and adapted to the exigencies of the case.

Sources of error, which in ordinary river work could be overlooked, must be eliminated as far as possible, or the results secured will not fulfill the purposes for which they are intended. Some of the physical difficulties encountered on the Sunnyside Project and the methods used to overcome them will be more or less applicable to all large irrigation systems.

Gauge heights, heretofore, have been used in all hydrometric work as a basis for determining the daily flow. From measurements of discharge by current meter at various stages a discharge curve is developed to which intermediate gauge heights are applied. Strictly speaking, gauge heights are an index of area only. Under permanent conditions of bed and banks, or when indicative of the head over some controlling obstruction, as a rocky ledge or a weir, gauge heights

are a fair indication of discharge. These conditions, however, seldom exist in earth sections.

The water in most irrigation canals carries large quantities of silt. This causes continual changes in the bed and banks, and consequently the gradient of the canal. Tumble-weeds and thistles are a source of endless trouble. They roll into the canal, are carried along by the current until they encounter an obstruction or become water-logged, or weighted with silt, and sink to the bottom. There they form the nucleus of an obstruction which continually enlarges, backing up the water until the increased pressure and currents carry them away. Such back-water effects are relatively small, but by no means negligible; yet their effect is indeterminate, and no corrections can be applied for them.

Wherever the velocity is retarded, the canals gradually silt up as the season advances, so that a gradually increasing back-water effect is encountered. In many places the growth of weeds and moss in the canal and along the banks produce the same back-water effect. Sweet clover is particularly troublesome. It grows luxuriantly along the banks, and, as the tops bend over and trail in the water, they soon become heavy with silt and seriously obstruct the channel. Such back-water effects are progressive with the season, and corrections are readily applied if a sufficient number of discharge measurements are made. For these reasons, gauge readings as reported are not an index of discharge, and only become so after corrections for these effects have been applied to them.

Gauge heights and the head on weirs are read and reported once a day. A single reading indicates only the rate of flow at the time of observation, and it is necessary to assume that this rate obtains for the entire 24 hours. This assumption, it will be shown, may lead to errors which are sometimes cumulative instead of compensating, as might be expected.

The delivery of water usually begins about April 1st, and, as the season advances, the head of water in the canal is gradually increased to the maximum requirement, which occurs about the middle of August. Crop requirements are variable, and these variations are largely taken care of at the waste-ways.

The operation of checks for keeping the water to levels required for delivery usually proves to be one of the most serious difficulties. These

checks are so numerous in the first 30 miles of the Sunnyside Canal that it is almost impossible to select a point for a gauging station which is not influenced by one of them. The difficulty arises from the variable back-water they cause.

If it were not for the weeds and trash, which, in spite of all precautions, will find their way into the canal and accumulate at these checks, no serious difficulty would be encountered at gauging stations within their influence, although the data to be gathered and analyzed, in order to correct for the back-water they cause, greatly increase the labor of computations. This accumulation of trash, and its subsequent removal, renders the control they exert on the flow an irregularly variable quantity. If this were not the case, the control would vary with some degree of regularity, and due allowances could be made.

Such severe conditions, of course, are seldom if ever met in river hydrometry, and it is on river requirements that the present hydrometric methods have been developed. It is true that in canals there is not a great range of stage with which to contend, yet the conditions within these stage limits are far more intricate than are encountered in river work, and require special treatment.

Methods Adopted on the Sunnyside Project.

The methods followed on the Sunnyside Project will be generally applicable to all cases where results of a fairly high degree of accuracy are required. The plan followed is by no means perfect, neither were the results secured as accurate as might be desired; however, they were sufficient for the immediate requirements, and marked a decided advance over ordinary river hydrometry.

In general, the methods were those at present practiced by the Water Resources Branch of the U. S. Geological Survey, except that each detail was carried to a greater degree of refinement.

Current-Meter Measurements.—The current-meter measurements were all made with the improved Small Price Penta-Meter, which indicates every fifth revolution of the wheel. The meter, at all except the shallow-water stations, was suspended on a single steel wire in order to reduce oscillations. A ground circuit completed the electrical connection with the telephone indicator.*

* "The Use and Care of the Current Meter, as Practiced by the United States Geological Survey," by John C. Hoyt, M. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. LXVI, p. 70.

Velocity observations were taken at two-tenths and eight-tenths of the depth, and the average velocity thus determined was taken as the mean velocity in the vertical. This method has proved to be the most reliable for general field practice, where depth of water will permit. In depths less than about 1 ft. the six-tenths method of determining velocity was used. Observations were taken at intervals not greater than 2 ft. across the stream.

As indicative of the accuracy of individual gaugings obtained in this manner, Table 2 shows comparative results of a series of measurements made simultaneously at some of the gauging stations. They were made for the purpose of comparing a Penta-Meter with a "Single Point" Meter.

TABLE 2.—COMPARISON OF METERS AND METER MEASUREMENTS, MADE JUNE 25TH TO 28TH, 1909.

Station.	Meter.	Area.	Discharge.	Difference:	
				Second-feet.	Percentage.
Intake	P 745	216	634	8	1.3
Intake	S 134	216	642		
8-Mile	P 745	237	620	9	1.4
8-Mile	S 134	237	611		
23-Mile	P 745	214	469	0	0
23-Mile	S 134	214	469		
28-Mile	P 745	209	466	3	0.6
28-Mile	S 184	209	469		
30-Mile	P 745	151	332	6	1.8
30-Mile	S 134	151	326		
32-Mile	P 745	143	323	3	0.9
32-Mile	S 134	143	326		

Gauges.—Several types of staff gauges have been tried. One graduated directly to hundredths of a foot by fine saw marks was found to be the best. The graduations are made on a clear piece of 1 by 3-in. board. For a space of 1 in. along one edge, the face of the board is slightly beveled, and the hundredth marks are first laid off in pencil on this beveled portion, and then sawed in a miter-box. The tenth and foot marks are made in the same manner on that portion of the face which is not beveled. The figures are stenciled in black paint.

In placing gauges, an arbitrary datum was used at each station, the only precaution being to place the gauge low enough to avoid negative gauge heights.

The gauges for reading the head of water on the weirs were made in 1-ft. and 2-ft. lengths. The graduations were in inches and eighths. Each was placed with its zero level with the crest of the weir. It is the intention to replace all weir gauges with a better type, reading to hundredths of a foot, but the water users under the old management had become accustomed to weir-heads measured in inches and the patrolmen's tables for individual allowances were in these units. For the sake of uniformity, therefore, the same units were used at diversions.

Four Lietz self-registering gauges were placed at favorable points along the main canal, in order to determine the extent of fluctuations and the error involved in using a single gauge reading for ascertaining daily discharge. They were placed respectively at the Intake, the 17-Mile, 28-Mile, and 42-Mile gauging stations. The staff gauges at these stations were reported the same as at all other stations, irrespective of the Lietz gauges. Some difficulty was encountered at first in keeping them running. The stylo-pens furnished by the manufacturers were found to be worthless, and not until soft pencils were substituted and the patrolmen became familiar with the peculiarities of the gauges were good results obtained.

The daily discharges at each of these stations have been computed from the patrolmen's records of single daily gauge heights, and also by using the mean daily gauge heights taken from the Lietz record sheets. The results are compared in Table 3.

From Table 3 it is seen that, taken by months, the errors of determining the discharge from single daily observations of gauge heights are compensating. In no case was the mean monthly discharge in error greater than one-half of 1%; but, in order to show how these errors may for certain periods tend to accumulate, Table 4 has been prepared for periods when the general change of stage was all in one direction. From this it is seen that even these are small, rarely exceeding 2 per cent. In general, the error should be positive for a falling stage and negative for a rising stage. This general tendency, however, cannot be detected when the stage is changing slowly and other complicating factors enter.

Computations.—Discharge curves were prepared in the usual manner,* and daily discharges were taken from rating tables made from the discharge curves. As soon as two or three measurements

* The methods used by the U. S. Geological Survey are described in the introduction to any one of Water Supply Papers, Nos. 201 to 214, or 241 to 252.

TABLE 3.—COMPARISON OF DISCHARGES, OBTAINED FROM SINGLE DAILY OBSERVATIONS, AND FROM LIETZ AUTOMATIC GAUGES.

Month.	Mean Monthly Discharges, in Second-Feet:		Difference:	
	Single daily observation.	Mean daily from automatic gauge sheets.	Second-feet.	Percentage.
Intake Station.				
May	611	609	2	0.3
June	618	620	2	0.3
July	662	665	3	0.5
August	686	685	1	0.2
September	617	616	1	0.2
17-Mile Station.				
May	540	545	5	0.9
June	526	527	1	0.2
July	603	600	3	0.5
August	585	585	0	...
September	508	507	1	0.2
28-Mile Station.				
May	477	476	1	0.2
June	474	474	0	...
July	520	520	0	...
August	511	512	1	0.2
September	465	464	1	0.2
42-Mile Station.				
May	202	203	1	0.5
June	220	219	1	0.5
July	228	227	1	0.5
August	238	238	0	...
September	235	235	0	...

TABLE 4.—ACCUMULATIVE ERRORS CAUSED BY USING SINGLE DAILY OBSERVATIONS FOR DETERMINING DAILY DISCHARGE.

Station.	Period.	Mean Discharge for Period:		Difference:	
		By single daily observation.	By automatic records.	Second-feet.	Percentage.
Intake	May 3d to 12th,	602	597	5	0.8
	June 22d to July 5th.	627	634	7	1.1
17-Mile	July 26th to August 2d,	591	585	6	1.0
	August 10th to 14th.	578	588	10	1.7
28-Mile	July 2d to 7th,	508	503	5	1.0
	September 16th to 22d.	397	402	5	1.2
42-Mile	May 6th to 10th.	194	197	3	1.5

were taken at any one station a provisional rating was made. This was revised from time to time as more data were secured. At the close of the season the entire field was reviewed, and new ratings were prepared, using the entire season's data, and all discharges were tabulated anew.

At only four stations was it possible to use the rating tables directly. At all other stations indirect methods had to be followed. This was due to silting, or the growth of weeds, causing back-water effects. Where these changes are progressive, the indirect method will give as good results as the direct, if a sufficient number of measurements are taken to define the correction curve.

Stout's indirect method* was the one followed. This was first used by O. V. P. Stout, Professor of Civil Engineering, University of Nebraska, to determine daily discharges in streams with shifting sandy beds. In effect it reduces the labor otherwise involved in the use of a number of rating tables, each applicable for a short period, and smooths the transition from one to the other. A rating table is prepared which gives, as nearly as possible, the relation between gauge heights and discharge if there were no changes in the rating. Then corrections are applied to the gauge heights before applying them to the table. The corrections are read from a correction curve in which the times are the abscissas and the differences between this rating table and the measured discharges are the ordinates.

The discharge and correction curves for the 52-Mile station on the Main Canal are shown on Plate XXXIX, and those for the Mathieson Lateral on Plate XL. At the 52-Mile station the corrections were made on account of back-water caused by the growth of weeds. Changes in the bed at the gauging sections also occurred, as will be seen from the cross-sections and area curves. In the Mathieson Lateral there was back-water, both from the silting up of the channel and the growth of weeds. The water was shut off from August 1st to 7th, and the lateral cleaned, which caused the sudden break in the correction curve. At both these stations the changes were progressive, and the results are nearly as reliable as if the direct method had been used. The conditions encountered and the methods used at certain gauging stations deserve special mention.

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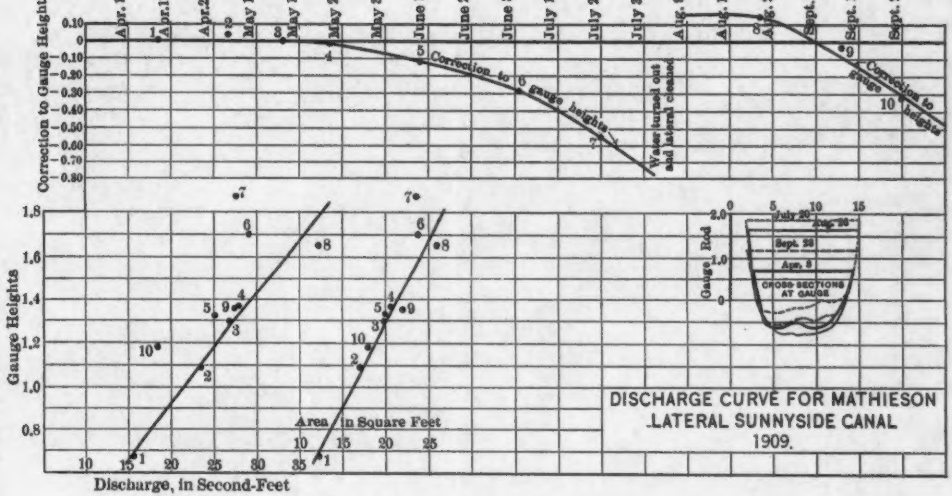
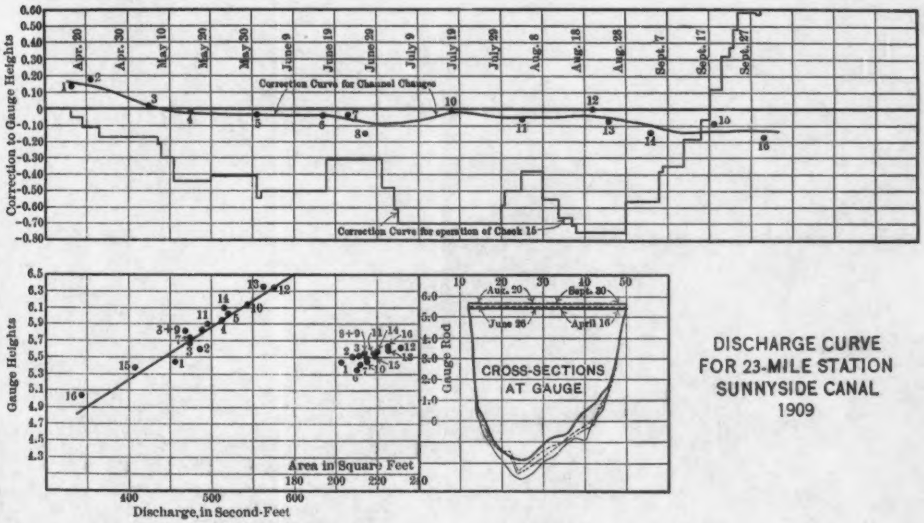
* Water Supply Paper No. 230, p. 10 *et seq.*



DISCHARGE CURVE FOR MATHIESON LATERAL SUNNYSIDE CANAL 1909.



DISCHARGE CURVE FOR 23-MILE STATION SUNNYSIDE CANAL 1909

23-Mile Station.—The conditions at the 23-Mile station were very complicated. Two sets of corrections were made, one for the back-water effect due to the operations of Check No. 15, located 2 000 ft. below the station, and the other for changes in the channel. A record was kept by the patrolman, on a card especially prepared for that purpose, of every alteration in the check and the effect it produced on the gauge at the gauging station. The gauge at the station was read immediately before each alteration and as soon after as the new condition of flow had become permanently established. This gave the effect on the gauge of altering the check, and these effects were algebraically added throughout the season.

The time between altering the check and observing the gauge at the station was dependent on the time at the disposal of the patrolmen. Sometimes an insufficient time was allowed and at others the time was so great that the actual flow in the canal may have changed. Hence, as to the alterations in the check alone, it was not always possible to determine their effect on the gauge at the station without including the effect of some other factor. However, the results were quite satisfactory considering the conditions under which they were obtained.

The lower half of Plate XL shows the essential features involved in computing the discharge at the 23-Mile station, as follows:

(1) The area of cross-section at the time of making the gaugings, plotted with the observed gauge heights. This shows how the water was kept at the same general level throughout the season.

(2) The algebraic sum of the corrections caused by check operations, producing the "correction curve for operations of Check 15."

(3) Discharge measurements plotted with gauge heights after correcting them for check operations, and the rating curve adopted.

(4) The cross-sections at representative times throughout the season.

(5) The correction curve for channel changes. These corrections were applied to the gauge heights previously corrected for check operations, before applying them to the rating table.

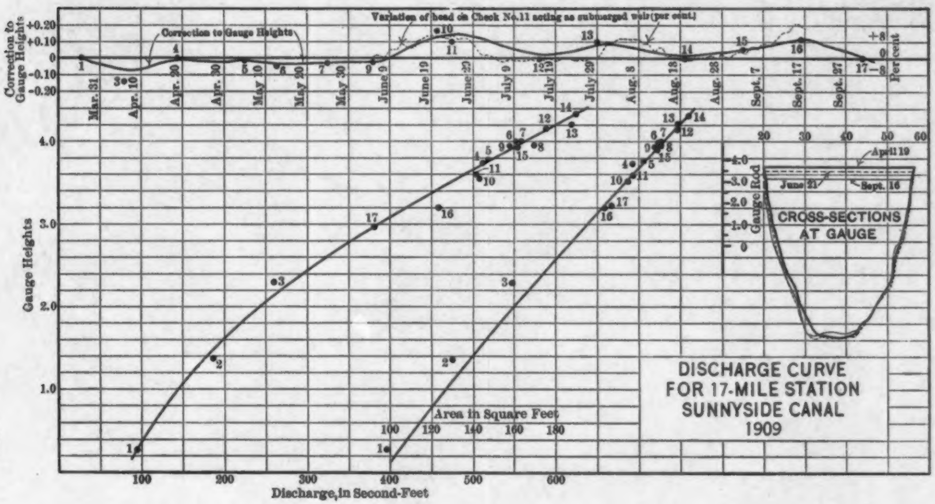
17-Mile Station.—At this station the change in rating is due to variable entrance velocities, the effect being very pronounced because the station is near the point of disturbance.

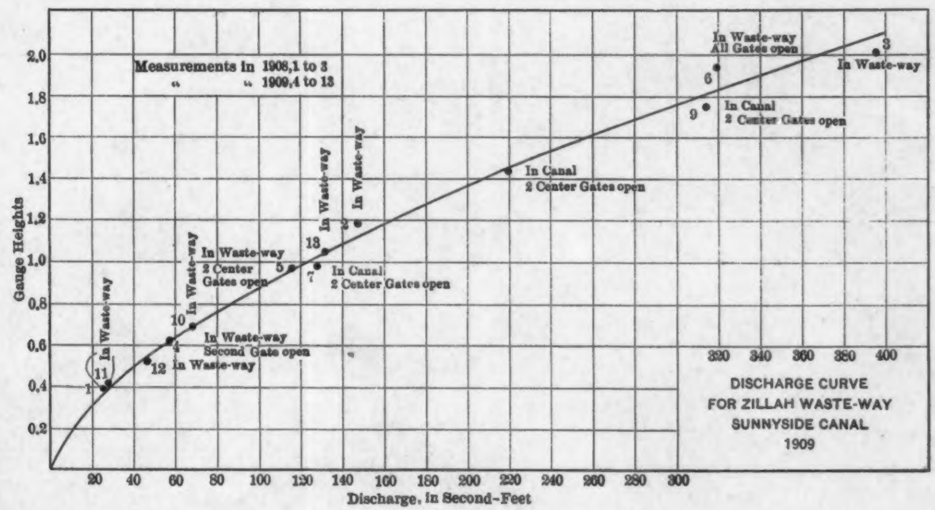
In line with the up-stream abutment to the waste-gates in the Zillah Waste-way there is a seven-panel check across the main canal. The 17-Mile station is 200 ft. below these combined structures. The flow in the canal below this check is regulated by the waste-way. The water on the up-stream side of the check was gradually raised throughout the season. On the lower side of the check the elevation of the water surface varied as the water was wasted. These fluctuations caused a changeable head on the submerged discharge area through the check, its action being that of a submerged weir. This created wide variations in the velocity of retreat which immediately becomes velocity of approach at the gauging station. In fact, these effects are analogous to the velocity of approach effect on weir discharge, the exact effect on the discharge being dependent on the distribution of velocities in the section of the gauge.

No data were obtained from which the actual head of water on the submerged portion of the check could be computed, but, by expressing the difference between the gauge readings at the 8-Mile and 17-Mile stations as a percentage, although the relations of the gauge datum are unknown, the relative variations in the head can be shown. This has been computed for each day from June 1st to September 15th, and the curve thus obtained is compared with the correction curve used at the 17-Mile station on Plate XLI. Note the general parallelism of the two curves. If specific data as to the variations in head on this check had been obtained, and the time of gauging the 17-Mile station had been selected with reference thereto, a much closer agreement could doubtless have been obtained; but this effect was not recognized until too late in the season to gather the necessary data. On this account, the indirect method has been applied in the usual manner.

Zillah Waste-way.—The Zillah Waste-way diverts water from the main canal just above the 17-Mile station. The first 800 ft. is an open concrete section, trapezoidal in form, which gradually decreases in bottom width and increases in slope. The station is located in a straight stretch, 200 ft. below the gates, where the bottom width is 9 ft., the side slopes are 1:1, and the gradient 0.003. A hook-gauge was placed in a stilling-box set outside the concrete lining and connected

PLATE XLI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXI, No. 1187.
STEVENS ON
HYDROMETRY AS AN AID IN IRRIGATION.





by a $\frac{1}{4}$-in. pipe, 6 ft. long, ending flush with the side and as near the bottom as possible. Variable velocities and great wave action may result, depending on the gate combinations used in diverting the water, so that the gauge heights are only an approximate index of the discharge. A record was kept of the gate openings and of the head of water on the openings, but they were found to be valueless for determining the flow on account of trash accumulations at the gates. Therefore, the direct method was used. The discharge curve for this station is shown on Plate XLI. Some idea is also given of the differences in gauge height for the same discharge which may result from different combinations of gate openings. Some of the discharges were obtained by direct measurement in the waste-way and some by measuring the main canal above and below the waste-way. Velocities as high as 21 ft. per sec. were measured with a current meter at this station.

Weirs.—Nearly all water diverted from the main canal was passed over trapezoidal weirs. The errors resulting from their use are very difficult to determine. Crop requirements are variable, and this necessitates continual adjustments of head-gates. The practice among patrolmen was to make adjustments of head-gates immediately after recording the head on the weir. It was impossible to have these adjustments made simultaneously over the entire system.

To measure properly, weirs must be kept in good repair, and the required conditions as to fall, contractions, etc., must be maintained. This is very difficult of accomplishment in practice. Newly placed weirs soon silt up, so that bottom contraction and sometimes end contractions are wholly or partially suppressed. Frequently the lateral below silts up or is so choked with weeds that water is backed over the crest of the weir. The eternal vigilance necessary to have kept all weirs in good order would have required the employment of a crew of laborers especially for that purpose. The patrolmen, however, were required to keep them cleaned at the headings as far as possible. In the distribution system, the burden of keeping weirs clean devolves on the individual water user. He rarely acts, however, until conditions are so bad that he cannot get sufficient water. This type of weir was calibrated by volumetric tests made in 1908.* These tests

* A description of these weirs, and the results of the experiments, may be found in *Engineering News*, August 18th, 1910.

gave rating tables differing considerably from the Cippoletti formula. The diversions in Beat 3 for April have been computed by the Cippoletti formula and also by the revised rating tables. The Cippoletti weir formula gives 29.61 sec-ft. for the average daily diversion, while the revised tables give 30.83 sec-ft., or 4% more. This difference is small, but is not negligible from the standpoint of distribution, for nearly all water delivered is ultimately measured over small weirs, there being more than 5 000 in use on the system.

Cost.

Careful records of the costs of the hydrometric work were kept on this project, and are summarized in Table 5. They do not include the services of a recording clerk nor the time spent by patrolmen in taking gauge readings. These men were regular employees of the Operation Department, and had many duties not connected with the hydrometric work. Otherwise these costs include all field work during the irrigating season, current analysis and reports, and the cost of the final analysis and report after the season closed.

TABLE 5.—Cost of Hydrometric Work on the Sunnyside Project, 1909.

	Amount.	Percentage of total.
Services, field	$506.61	23
Computations	763.32	35
Administration	321.42	15
Lost time (Sundays, holidays, annual leave, etc.)	201.42	9
Traveling expenses	272.16	13
Supplies and equipment	110.10	5
Total	$2 175.03	100

Number of gauging stations maintained	23
Cost per station	$94.50
Number of gaugings made	266
Cost per gauging	$8.18

Application to Operation Requirements.

In order to make the data secured of the greatest use in operation, it is necessary that the results be worked up as rapidly as they accrue. If the direct method of applying daily gauge readings to discharge curves could be used throughout, this requirement could easily be met; but, for stations in earth sections and within the influence of

checks and other disturbing factors, some indirect method must be used, as long as gauge heights alone are depended on as an index of discharge. Discharge measurements must be made at frequent intervals and at critical times. It is obviously impossible to determine the proper corrections to be applied to gauge heights on any one day until the measurement at the end of that time interval has been made. To make a meter measurement every day at each station is out of the question. The period which may safely be allowed between times of gaugings will depend on the stability of conditions at that station; but, in general, from ten to fifteen days may be regarded as the limit.

In preparing discharge data for current uses, the only method that can be followed is to estimate from known conditions and the corrections indicated by the gauging last made, what corrections to gauge heights are necessary. This will enable the hydrographer to prepare daily reports showing approximately the disposition of water in the system. At the end of the week or month it is possible to revise the rating tables and correction curves, and approximate the truth more closely. At the end of the season all tabulations are made anew, and final adjustments permit the elimination of all errors as far as possible. The labor involved in this process is great, for the estimates for some stations may require revision ten or more times. However, a little practice, and the adoption of some short-cut methods, enabled the hydrographer with one clerical assistant to keep the computations up to date.

For daily requirements approximate results are sufficient, because they are used chiefly for the distribution of water in the main channels day by day. The weekly and monthly reports are revisions, and serve for a broader study of distribution to certain areas or to certain crops. The final seasonal report furnishes data whereby the general efficiency of the season's operation can be studied. The lessons learned from one season's operation are thus utilized in planning the next season's work.

Under the Sunnyside Project, sufficient data on crop statistics and crop requirements had not been secured previous to 1909 to render the discharge data of the highest possible use. The acreage irrigated varies day by day and month by month, and this variation should be known in order to operate the system efficiently. The acreage in the various crops had not been secured except in a very general way. It

takes a great deal of time to gather all these statistics and to keep them up to date. On this project steps are being taken to gather very complete data of this nature, but they are not available for study in connection with the discharge data secured in 1909. On this account, only general lessons can be drawn from that season's operation.

Table 6 shows the monthly and seasonal disposition of all water received at the intake. The unit is the acre-foot. It also shows the quantity wasted through operation and the quantity delivered to the water users. The latter is an approximation, and includes the error of estimating the seepage losses in the distributing laterals.

TABLE 6.—SEASONAL DISPOSITION OF WATER RECEIVED AT THE INTAKE OF SUNNYSIDE CANAL IN 1909.

	April 16th to 30th.	May.	June.	July.	August.	September 1st to 15th.	Total.
Water received at intake, in acre-feet	17 190	37 400	36 830	40 820	42 060	18 300	192 600
Wasted in operation, in acre-feet	907	655	2 416	915	2 101	1 077	8 070
Wasted in operation: percentage	5.3	1.8	6.6	2.2	5.0	5.9	4.2
Losses from main canal (seepage, etc.), in acre-feet	2 776	5 643	5 015	7 453	8 324	3 441	32 650
Losses from main canal: percentage	16.1	15.1	13.6	18.2	19.8	18.8	16.9
Diverted into distributing laterals, in acre-feet	13 640	31 130	29 380	32 240	31 670	13 830	151 900
Diverted into distributing laterals: percentage	79	83	80	79	75	76	79
Estimated loss in distributing laterals, in acre-feet*	1 857	4 148	4 017	4 358	4 324	2 093	20 800
Net amount used on lands, in acre-feet	11 780	26 990	25 360	27 890	27 340	11 740	131 100
Net amount used on lands: percentage	67	72	69	71	65	64	68
Acres irrigated	......	......	......	......	......	......	47 000
Depth of water applied, in feet	......	......	......	......	......	......	2.79
Rainfall, in feet	0.001	0.015	0.016	0.043	0	0.002	0.077
Total depth received by the land, in feet							2.87

* Loss in distributing laterals assumed as follows:
5%, intake to 17-Mile; 10%, 17 to 30-Mile; 15%, 30 to 52-Mile; 25%, below 52-Mile. These values follow from the investigations of seepage made in 1908 on certain laterals chosen for that purpose.

Table 6 is worthy of study. It shows that 68% of the water diverted from the Yakima River was delivered to water users and that 28% was lost by seepage, of which 17% applies to the main canal and 11% (estimated) to the distributing laterals. This, of course, is

not "seepage," in the strict sense of the word, for it includes evaporation and the uncompensated errors of observation and measurement. In regulation, 4% was wasted.

The percentage of water diverted into the distributing laterals by months is a fairly good measure of the efficiency of the system. This had its maximum value of 83% in May. During this month the canal is free from weeds, all weirs are in good measuring condition, and the head in the canal is not excessive. August is the least efficient month, for the canal is crowded to its maximum capacity to supply the demand for water, the carrying capacity of the laterals is relatively low, and the losses are consequently high.

Table 6 also indicates that the lands under the canal received water equivalent to a total depth of 2.87 ft. during the season of 5 months. This figure is obtained by dividing the total quantity of water delivered to distributing laterals by the total acreage, after making reasonable allowances for seepage. It is somewhat doubtful whether or not the lands received all of this water, because the disposition of water on individual tracts is not known, but, if they did, it surely represents a great waste. It means that there were applied to the land large quantities which did not benefit the growing plants. In the irrigation of alfalfa, for instance, the frequent practice is to run the water in long furrows. Before any water has reached the farthermost end of the field, the soil at the upper end has become saturated to depths far beyond those required by plant roots. This can be remedied by running the water in shorter furrows, by the use of additional heading ditches, or by using a sufficient head of water to carry it to the farther end quickly. The latter plan is by far the better, but, under the continuous-rate method of delivery, it is frequently impossible, because of lack of sufficient water at one time. As a general thing, water can be saved by giving the irrigation a large volume for a short time rather than a small volume for the entire season. A plan of rotation can frequently be effected by mutual agreement among those irrigators drawing water from the same lateral. Sufficient water is delivered to the head of the lateral, at a continuous rate, to furnish the contract allowances for all land under it. The irrigators then agree among themselves as to the times of distribution, and arrange a schedule of delivery accordingly. The water is distributed by the patrolman in accordance with these agreements. On

some of the newer projects this plan has been adopted with excellent results, but, on the Sunnyside Project, there are several different contracts outstanding, as the Government assumed to carry out all contracts in force between the former owners of the system and the water users. On this account it has been very difficult to put improved methods into practice, although the necessity for adopting them is fully realized.

The engineering difficulties connected with the development of such a system are entirely eclipsed by the "human problems" encountered in operation. The human tendency has always been to take everything that is due—and more. If an irrigator is by contract entitled to 1 sec-ft. of water, he is likely to insist on having that quantity delivered whether or not he has use for it, even knowing that its application to his land would practically ruin his crops. He fears that by a relinquishment now he would forfeit his right to the water in the future. This human tendency will always be a source of trouble as long as water is delivered at a continuous rate. Some of the newer contracts allow so many acre-feet per acre per annum, or so much thereof as may be necessary for the production of crops, but the farmer is usually the judge as to the necessary quantity. While these provisions have certain advantages, the evil will never be cured until the irrigator is required to pay, according to a properly graduated scale, for the actual quantity of water used.

Another "human problem" encountered by the new administration was very satisfactorily solved after some experimental work had been done: The Sunnyside type of weir delivers from 2 to 8% more water than would be delivered over a sharp-crested steel weir under the same head. This was determined by calibrating the two types by volumetric tests. Each water user's allowance is calculated for him in inches of head over his weir, and each irrigator, of course, knows the number of "inches of water" to which he is entitled. In order to limit each irrigator to the exact quantity allowed to him, it would have been necessary to reduce slightly the head allowed each. The reason for such a reduction could never be explained to the layman, and would have brought forth very bitter protest, and probably litigation would have followed; but, by substituting a weir sheared from thin steel plate, each irrigator could still get the same head of water over his

weir, but not the excess water to which he had become accustomed. The reduction in individual cases could hardly be detected, but in the aggregate a saving of nearly 4% of the water supply would result. The steel weir is being installed on the new work of the project, and is gradually being substituted for the old type in present structures.

In designing an irrigation system, as well as a power-plant, it is necessary to provide for the "peak load." In power-plants this feature usually becomes the major item in the cost of operation. In irrigation, however, the situation in this regard is rarely so acute. The maximum demand may continue for 15 or 20 days, and, by judicious management, it is frequently possible to extend it over a longer period. The carrying capacity of a canal and distributing laterals, and thus the cost of the project, is largely fixed by the maximum requirement. By intelligent distribution of the water, with regard to the time of irrigating the various crops, and by encouraging the water users to plant a diversity of crops, this peak can be broadened, thus reducing a rate of flow that otherwise might be difficult to maintain. For instance, alfalfa requires a greater quantity of water than most other crops. Under the same project, this crop ripens and is cut at about the same time. It is irrigated after each cutting. Under the Sunnyside Project, three cuttings are secured, hence, if the entire area was cropped to alfalfa, there would be three "peaks" to the distributing load during the season, and they would be so high that it would be impossible to supply the water, with the present ditch capacities; but, where alfalfa fields alternate with orchards, potatoes, beets, timothy, clover, small fruit, etc., the demand is much more uniform. The extent to which conditions in this regard can be improved by encouraging diversified farming among the irrigators, is somewhat surprising. To do this effectively there is need for exhaustive and systematic study of the most efficient duty of water, for different crops and for different soils. Only the most general results have been secured in this line, up to the present time, nor is it possible to secure more specific data elsewhere than on the project where the data are to be utilized.

An experimental irrigation farm should be as much a part of the equipment of a large irrigation system as the ditches themselves. Such a farm should be placed in charge of a skilled agriculturist, and then the results should be presented to the water users in an attractive and forceful manner.

Fig. 1 shows the hydrographs obtained at all stations on the Sunnyside Project during the season of 1909. These illustrate the "peak loads" for that project. The solid lines represent the inflow into each beat. The dotted lines represent the outflow plus the diversions in each beat. The differences between these two curves, shown as shaded areas, represent losses. They are numbered to correspond with the beat numbers, as given in Table 1.

The volume carried by the canal is regulated at the intake and at the Zillah Waste-way, just above the 17-Mile gauging station. The lands above the 23-Mile station are nearly all in orchards, while below this point alfalfa is the prevailing crop. The effect of the necessary manipulation of the Zillah Waste-way to supply the variable demand for alfalfa irrigation is well illustrated in the 23-Mile hydrograph (Fig. 1). The first irrigation of alfalfa occurred during May. Cutting began about the middle of June, and water had to be wasted or lands at the lower end of the canal would have been damaged and the safety of the canal menaced. As soon as the alfalfa was cut, the fields required another irrigation, which began about July 5th. The second cutting was made early in August, and irrigation of the cut-over fields began about August 15th. The third cutting began about September 15th, and other crop requirements began to fall off, which necessitated shutting down the supply very suddenly.

The gates to individual measuring boxes are arranged so that the water user may shut off his supply at will, but he cannot open it to deliver more than a certain quantity without breaking a padlock and subjecting himself to penalties. The result is that considerable quantities are frequently turned into the main canal without the knowledge of the management, although patrolmen are always on the watch for such an emergency. The head-gates of laterals are being adjusted continually, and this requires continual adjustment at the head and waste-way in the main canal. At the time of maximum requirement—August 14th to 26th in 1909—the situation in this regard became very acute, for the canal and laterals were almost to the breaking point in many places, and a few second-feet more would cause serious damage.

Table 7 shows the monthly and seasonal average of the inflow, outflow, diversions, and losses in 1909 on the Sunnyside System, considered in four principal sections. The sections are, respectively, 30, 18, and 12 miles in length, for the main canal, and 9 miles for the

HYDROGRAPHS OF SUNNYSIDE CANAL, 1909

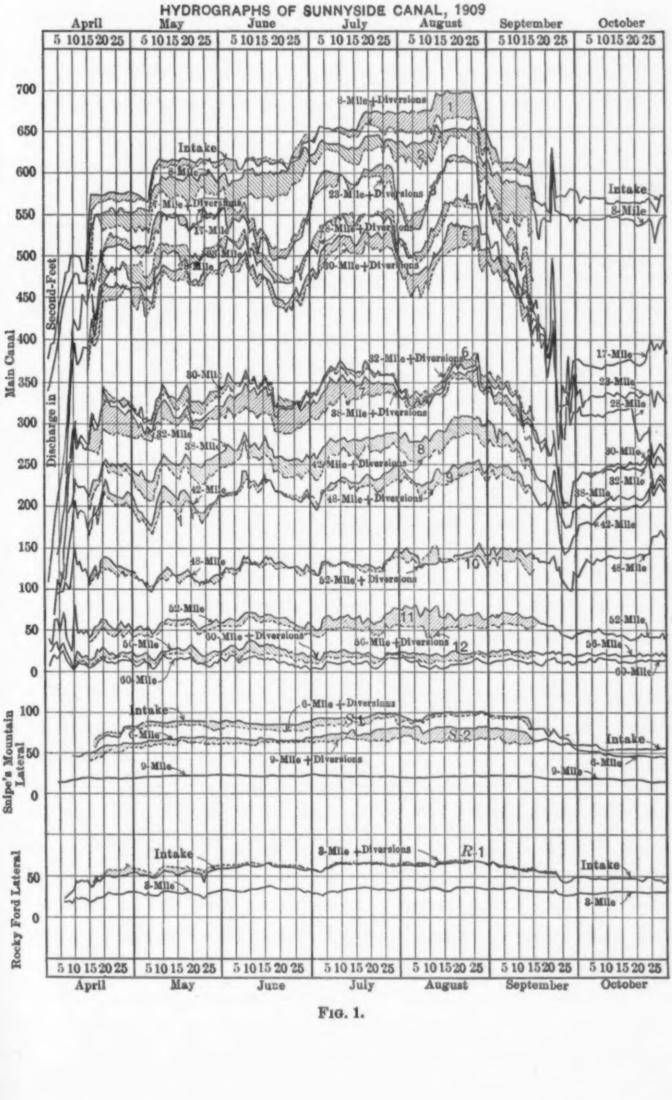


FIG. 1.

principal lateral. For general use, the losses are expressed in percentages of the inflow into each section, and in second-feet per acre of wetted area in the bed and banks of the canal. Seepage is not properly expressed as a percentage of flow, because it may occur from a still pond, but it is given because it is a convenient unit and is useful for relative comparisons.

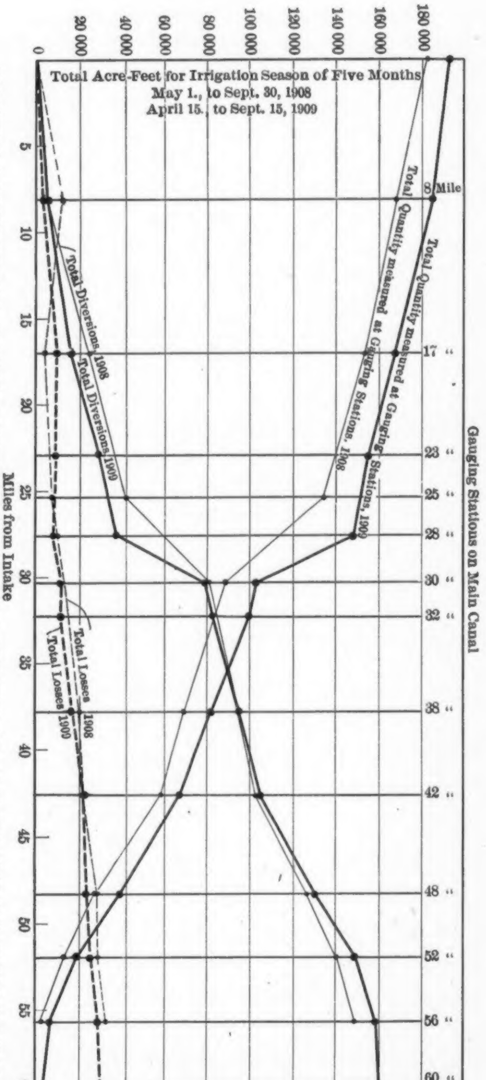
The losses shown in Table 7 are not seepage alone, but include the uncompensated errors of the methods used; hence daily losses, as shown in Fig. 1, will be more variable than monthly averages, and should not be used for general deductions. Observing this precaution, it is seen, from Fig. 1 and the foregoing tables, that the maximum flow in the main canal at the head was 11% greater than the average for the season. The highest diversion in one month into the distributing laterals of the system was 8% greater than the average for the season, while the average losses for the month of greatest diversion was 38% greater than the average losses for the season. This disproportionate increase in the losses with an increase in the flow of the canal and laterals is very striking, and indicates the necessity of keeping the demand as nearly uniform as possible.

Fig. 2 shows the seasonal disposition of all water received at the intake of the canal. For purposes of comparison, the results for 1908 are also given for the same length of time, except that the period began 15 days earlier.

The foregoing tables and figures show briefly the results of hydrometric work secured on the Sunnyside Canal in 1909. This work is being continued as an operation adjunct. In connection therewith complete crop statistics are being gathered, and it is likely that these data, taken together, will reveal the wastefulness of certain present-day practices and suggest methods whereby the efficiency in operation of such a large system can be continually improved. Hydrometry is seen to be at the foundation of any investigation of this nature, but its use in this connection is comparatively new. The exigencies of the case demand a much higher degree of accuracy than heretofore has been considered possible. Yet if refined methods can be adopted and practicable results secured it offers a possible method of determining the flow in many canals, which, on account of low gradients, could not be measured in any other way.

TABLE 7.—INFLOW, OUTFLOW, DIVERSIONS, AND LOSSES IN FOUR PRINCIPAL SECTIONS OF SUNNYSIDE CANAL, IN 1909.

	April 16th to 30th.	May.	June.	July.	August.	September 1st to 15th.	Mean.
MAIN CANAL:							
Intake to 30-Mile.							
Inflow	579	609	620	665	685	616	636
Outflow	314	329	338	360	347	326	340
Difference	265	280	282	305	338	290	296
Diversions	230	255	264	262	272	246	258
Losses, in second-feet	35	25	18	43	66	44	38
Losses, in percentage of inflow	6.0	4.1	2.9	6.5	9.6	7.1	6.0
Wetted perimeter, in acres	154.8	155.8	155.5	158.6	160.6	155.6	156.8
Losses, in second-feet per acre	0.226	0.160	0.116	0.269	0.412	0.283	0.242
30-Mile to 48-Mile.							
Inflow	314	329	338	360	347	326	340
Outflow	125	112	128	128	137	144	129
Difference	189	217	210	232	210	182	211
Diversions	146	169	169	185	181	158	171
Losses, in second-feet	43	48	41	47	29	24	40
Losses, in percentage of inflow	13.7	14.6	12.1	13.4	8.4	7.4	11.8
Wetted perimeter, in acres	71.1	71.0	72.1	81.5	81.6	79.5	76.1
Losses, in second-feet per acre	0.605	0.676	0.568	0.577	0.355	0.304	0.526
48-Mile to 60-Mile.							
Inflow	125	112	128	128	137	144	129
Outflow	10	10	11	7	7	9	9
Difference	115	102	117	121	130	135	120
Diversions	95	88	100	103	106	105	99
Losses, in second-feet	20	14	17	18	24	30	21
Losses, in percentage of inflow	16.0	12.5	13.3	14.1	17.5	20.8	16.3
Wetted perimeter, in acres	23.9	23.9	25.5	24.9	26.9	25.9	25.2
Losses, in second-feet per acre	0.837	0.586	0.667	0.723	0.892	1.16	0.837
SNIPE'S MOUNTAIN LATERAL:							
0 to 9-Mile.							
Inflow	70	86	82	93	95	90	89
Outflow	18	20	20	20	20	20	20
Difference	52	66	62	73	75	70	69
Diversions	48	57	54	56	59	56	57
Losses, in second-feet	4	9	8	17	16	14	12
Losses, in percentage of inflow	5.7	10.5	9.8	18.3	16.8	15.6	13.5
Wetted perimeter, in acres	18.3	19.0	19.1	19.1	20.1	19.5	19.2
Losses, in second-feet per acre	0.22	0.47	0.42	0.89	0.80	0.72	0.63



DISPOSITION IN SUNNYSIDE CANAL OF WATER RECEIVED AT INTAKE DURING IRRIGATION SEASON OF FIVE MONTHS IN YEARS 1908 AND 1909

FIG. 2.

It has been estimated that 1 sec-ft. of water applied to lands under the Sunnyside Project creates for them a valuation of $80 000. Every second-foot of water, therefore, which by judicious management can be transferred from waste to beneficial use, increases the taxable property of the State that much, and adds its due proportion of homes to the social system.

It would seem, therefore, that almost no limit of accuracy should be recognized for hydrometric work on an irrigation system, because hydrometry is the essence of conservative operation. The fact remains, however, that canals have been operated after a fashion with only the crudest general knowledge of the flow. Such methods are not destined to continue, for, although the water supply may be bountiful and the prevention of waste an unnecessary expense, systematic hydrometric work is not the less important. The excessive use of water on land is a most harmful practice, for, not only is the immediate owner depriving himself of profits which a more conservative use would insure, but he frequently works untold injury to his neighbors. Examples of this pernicious practice are only too numerous. It is practically certain that irrigated lands, the country over, would produce more and better crops if less water was used, and more attention was given to cultivation and the times and manner of irrigation. In determining the most effectual quantity of water for different crops and different soils, and in the proper delivery of this quantity after determination, the highest possible degree of accuracy in canal hydrometry must be attempted.

DISCUSSION.

Mr. Chandler. E. F. CHANDLER, Assoc. M. Am. Soc. C. E. (by letter).—This paper shows that systematic changes in rating tables may be caused by the growth of vegetation in canals during the "growing season." The frictional coefficient being thereby increased, the velocity is retarded, and, if the discharge remains constant, or even if it diminishes somewhat, the gauge height may increase from month to month. At the opening of the next season, after the channel has been cleaned by the winter frosts, or artificially, the flow is again more rapid at a lower gauge height.

In northern regions, in many natural streams of slight fall, where the spring run of ice carries away the vegetation, the same thing occurs. A very striking illustration of this has been taken from the records of a gauging station maintained for a time by the U. S. Geological Survey on the James River, at LaMoure, N. Dak. This river has a fall of much less than 1 ft. per mile, and, through a large part of the year, the discharge is so small as hardly to entitle it to the name of "creek," although its early spring flow is sometimes about 1 000 sec-ft. The weeds growing in the channel are locked in ice 2 ft. thick during the winter, and are torn loose when the ice rises in the spring, so that the stream begins the season with a comparatively clear channel.

By placing the gauge zero near the bottom of the channel, the following discharge measurements were obtained:

May 8th, 1903, gauge height, 4.0 ft.; discharge, 127 sec-ft.
July 29th, 1903, gauge height, 5.2 ft.; discharge, about 10 sec-ft.

At such a station, although an abrupt change in gauge height would indicate change in discharge, the gradual change throughout the season is merely an indication of the luxuriance of the growth of vegetation. By frequent discharge measurements, there could have been determined, at short intervals, the values of a systematic correction to be applied to the gauge heights, as done by Mr. Stevens, but this would have added to the expense of maintaining the station an amount disproportionate to the value of the record at that point; hence, it is needless to explain that the station was discontinued on July 30th.

In river record work, it is usually unnecessary and inadvisable to locate permanent open-season gauging stations where such causes operate; hence corrections of this class have not been studied as thoroughly as their importance warrants, for in canal work this effect is often noticeable.

It may be remarked that this same method of applying systematic corrections to the gauge height, as deduced from frequent discharge measurements, is a convenient means often used for applying rating

tables to gauge-height records during the winter, in Dakota, where the velocities are slow, and the ice is therefore usually fairly smooth on the lower surface, giving a fairly constant frictional resistance during the winter; but, where the ice becomes thick, its thickness and also the frictional resistance caused by it are very important factors to be considered in summarizing the flow. Mr. Chandler.

C. E. Shipman, Assoc. M. Am. Soc. C. E. (by letter).—The author mentions a matter which is exceedingly important, when he points out, as a "human problem," the tendency of most irrigators to take all the water they can get, even though their crops do not need it and their lands may be ruined thereby. The results of such a tendency are very well illustrated in the Yellowstone Valley near Billings, Mont. Some sections of this valley have been irrigated for 25 years or more. The principal crops are alfalfa, oats, and sugar beets. The Yellowstone River carries an abundant supply of water, the canals are of ample size, and except when, as during the latter part of 1910, the river falls below the head-gates, there is never any scarcity of water. The ranchers, therefore, have used, or attempted to use, twice or three times as much water as their crops required, and as a result, hundreds of acres which formerly produced two or three crops of alfalfa, now produce nothing but cattails and mosquitos, and are practically worthless. Mr. Shipman.

Some attempt has been made to remedy these conditions by the construction of drains, under the provisions of a State Drain Law. These are usually box-drains, placed far enough below the surface to tap the gravel which underlies the valley and carries a large quantity of water; they are generally from 5 to 10 ft. deep. These drains have been very successful, but their cost is enormous, in some cases equal to or exceeding the cost per acre of the irrigation system. The writer believes that if an attempt had been made to ascertain in some manner the quantity of water actually delivered to each irrigator, much of the trouble would have been eliminated; and he is of the opinion that much of the value of such data as the author has collected concerning the Sunnyside Canal, is in the opportunity afforded for detecting wasteful and excessive use of water.

Undoubtedly an irrigation canal should be "metered," and the water sold at so much per acre-foot. In too many cases, the method of measurement has been the "eye" of the ditch rider, assisted by a "Konnewock" of some description, and while he may have been able to divide the entire quantity of water flowing in the canal among the water users in proportion to their respective shares, it has not been shown that he did not give each user 50 or 100% more than his shares called for and his crops required.

The average land-owner would probably say that such methods as the author describes are too expensive, and that no one but the Government can afford to adopt them, but, according to the cost data given

Mr. Shipman. in the paper, the cost for 1909 amounted to about $4\frac{1}{2}$ cents per acre, certainly a very reasonable figure.

The writer notes that in Table 6, the losses from the main canal from seepage, etc., are given as 16.9%, which would indicate that the usual allowance ($\frac{1}{2}$% to 1% per mile) is excessive. The total loss in main canal and laterals combined, 32%, is almost exactly $\frac{1}{2}$% per mile of main canal.

The writer believes that on the irrigation systems constructed and operated by the United States Reclamation Service a more intelligent effort has been made to determine the actual quantity of water used than has been customary on private projects, and that these private projects will find it necessary at no very distant date to adopt more accurate methods than they have used heretofore.

Mr. Herschel. Clemens Herschel, M. Am. Soc. C. E. (by letter).—The writer will take for his text this sentence from Mr. Stevens' admirable paper:

> "The time is not far off when the water used on these large systems will be distributed as carefully as under the metered systems of large cities, where patrons pay only for the water they use."

Instead of the tenth word of this sentence being "used," however, it should be "consumed," which is the accepted term for use, plus waste.

Irrigation is one of the oldest forms of the use of water by Man, dating back thousands of years. Copies, engraved on stone, of the rules established in Roman times for dividing irrigation water among the owners of certain lands, have been dug up, and show that the division was by designated hours' run, of certain watercourses. With this method, there were crude devices for halving, or otherwise roughly dividing streams of water.

In the 16th century, in Italy, the first attempts were made to allow only a fixed quantity of water to flow on a certain piece of land, whether or not the level of the water in the main or branch ditch varied materially. This was done with the so-called modules; and now at length we are on the brink of alloting, by measure, the water consumed on the premises of the land-owner or farmer; without which, as will presently appear, there can be no proper and economical use of the water applied to the land.

This results from certain attributes of human nature, unchangeable through the centuries past and to come. No man will work industriously to attain a maximum result from the application to the land of a minimum of water, unless he pays for such use according to the quantity consumed.

Again: No man will take pains even to shut off the flow in his irrigation ditch when he is not using it, if it costs him no more to let it run. More than this: He will enjoy letting it run to waste through his land, as long as he has the right thus to let it run.

From studies made by the writer, on the basis of experiments in the arid lands of the United States, he has become convinced that greater crops per acre could be raised in this country, if only half as much water per acre were used in irrigation. Mr. Herschel.

The full meaning of this result of irrigation experiments in the United States is not at once apparent. If 500 cu. ft. per sec. be devoted to irrigation, and the water is sold or let as has been done hitherto, they will irrigate, let us say, 2 000 40-acre farms; but, in order to get the maximum crops per acre, they should be made to irrigate 4 000 40-acre farms.

Assume the cost of the "system," water-rights, dam, main ditch, main branches, etc., to be $2 400 000, then we shall get poor or mediocre crops on 80 000 acres, on which $30 per acre has to be paid as the price for water, instead of getting a maximum of crops per acre on 160 000 acres, at the same total cost for water-rights, dam, main ditch, etc., and with a tax of only $15 per acre. In one case the 40-acre farmer has paid $1 200 for water, and raises poor crops; while, in the other case, the 40-acre farmer pays only $600 for water, and raises the maximum yield per acre of which the land and crop raised are capable.

It will be seen that the importance of all this to the State and to the Nation can hardly be overestimated, especially when it is considered that while there is plenty of arid land, there will always be a limited supply of water to irrigate it.

Now, as human nature, or selfishness, is unchangeable, as far as observations have gone, there is only one way to produce this great and widely beneficial improvement in irrigation farming. Each farmer must pay for water according to the quantity used and wasted on his premises; with a limitation as to the maximum quantity which he may draw at any time, so that the ditches will not be overburdened by too many parties making an overdraft at the same time. To charge ten times the sum for overdraft which, otherwise, would have become due on account of lawful draft, has proved to be, in water-power administration, a sufficient deterrent to keep parties within their lawful quantities.

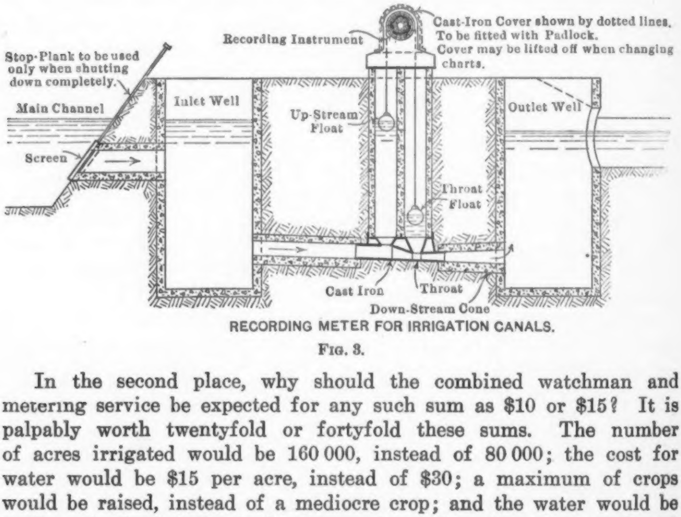
Passing on to practical matters: No system of watchmen, or ditch riders, or hydraulic engineers armed with the clumsy implements of their hydrometric profession, such as current meters, Pitot tubes, weirs, and the like, will be able to enforce obedience to local laws, such as have been described. All these work too slowly, and to carry out the allotted task in this way would cost absurd and impracticable sums. The only practical way is to apply to every 40-acre farm a recording meter, which then becomes both a meter and a day and night watchman for each farm.

Such meters have been in use to measure other water, these 20 years or more, and need not now be invented, but they must not be

Mr. Herschel.

expected in answer to the mistakenly conservative saying: "When we can get meters for $10 or $15 apiece, we will meter irrigation water."

In the first place, no mere meter will ever accomplish the desired end. It must be a recording meter, having watchman-like qualities, which are fully as valuable in the considered position as is its meter work. Fig. 3 shows such a meter, devised by the writer, for irrigation purposes. The charts on the recording instrument are 12 in. in diameter, and record "cubic feet per second" continuously. The total number of cubic feet is determined by measuring the chart with a planimeter. Each chart represents a run of 7 days.



RECORDING METER FOR IRRIGATION CANALS.

FIG. 3.

In the second place, why should the combined watchman and metering service be expected for any such sum as $10 or $15? It is palpably worth twentyfold or fortyfold these sums. The number of acres irrigated would be 160 000, instead of 80 000; the cost for water would be $15 per acre, instead of $30; a maximum of crops would be raised, instead of a mediocre crop; and the water would be used on the land, instead of being partly used, and partly wasted, and drowning out other lands by seepage.

Such results should not be expected for $10 or $15 per 40-acre farm; they would be cheap at $200 or $400, or still more, per 40-acre farm.

Mr. Follansbee.

ROBERT FOLLANSBEE, Assoc. M. Am. Soc. C. E. (by letter).—The writer wishes to emphasize the idea brought out by Mr. Stevens, that, unless more refined methods are used, the work of measuring the flow in irrigation canals will give much less accurate results than measurements of rivers.

In 1906 and 1907 the writer was in charge of the water resources investigations of the U. S. Geological Survey in Montana. There were about seventy-five gauging stations in the district, including those on a dozen irrigation ditches. Almost without exception, these latter

stations were subject to such changing conditions of flow, due to the silting up of the channel, use of check-gates, sudden changes of flow due to operation of head-gates, etc., that it was not possible to utilize the ordinary methods for river stations. It was necessary to have measurements made at intervals ranging from 1 to 2 weeks during the operating season. On most of the canals the staff gauge was read at least once a day, and oftener when the head-gates were changed. Wherever possible, the head-gate tender read the gauge, and thus knew when the gates were changed. The daily discharge was computed from a series of rating curves, each applicable for a short time only. Mr. Follansbee.

Not only is it more difficult to secure accurate records of flow in irrigating canals, but the need for more accurate records is greater than in the case of rivers. In the latter, the object of the records is to forecast the future flow, and as this has a wide yearly variation, a high degree of accuracy would not enable the forecast to be made any more correctly. Thus, as pointed out by Mr. Stevens, river records answer the chief purpose for which they are intended, if they are within 10 per cent.

The chief use of canal records, however, is to show the quantity of water available for the different users, and, in connection with waste measurements, to show the actual quantity used in irrigating a given crop. As water is one of the most valuable of the natural resources in the arid and semi-arid sections, it is essential that the information for irrigation canals be more exact than that for rivers.

J. C. Stevens, Assoc. M. Am. Soc. C. E. (by letter).—As published in *Proceedings,* the term "hydrography" was used in the title and elsewhere in this paper. Mr. Clemens Herschel has suggested the subsitution of the word "hydrometry" for "hydrography" wherever it appeared. The writer hesitated at first to make the change, in view of the fact that the term "hydrography" has been generally associated in the United States with this class of work. He has long felt, however, that the change was desirable. Mr. Stevens.

Two branches of the Government service have used "hydrography" to denote two distinct lines of work. The Hydrographic Office of the Navy uses it as descriptive of harbor and shore line soundings, while the Geological Survey uses it to denote the measurement of flowing water. In the latter sense it is a misnomer. The term "hydrometry" correctly describes work of this character, and it is used in this way in other countries. The writer, therefore, welcomed the suggested change, but, as he did not wish to "be the first by whom the new are tried, nor yet the last to lay the old aside," he brought the question to the attention of the engineers of the Geological Survey at a recent Conference of District Engineers, held at Washington, D. C.

After some discussion, a resolution was adopted favoring the use hereafter of the word "hydrometry" as descriptive of that class of work heretofore designated by them as "hydrography."

Mr. Stevens.

Accordingly, the writer willingly accepts Mr. Herschel's suggestion, and hopes that other engineers will follow the example.

The feature discussed by Mr. Herschel is one of great importance. The writer concurs in his statement that larger and better crops could in general be secured if only half as much water were used per acre, provided, however, that greater attention be given to the time and manner of cultivation. It is less laborious to turn on the water than it is to cultivate, and in many sections the tendency is to substitute irrigation for cultivation. A maximum efficiency in farming can only be secured through intensive scientific cultivation coupled with the use of a minimum quantity of water. However, this doctrine could be preached from now until doomsday, by all the hosts of agricultural experts the country could supply, without tangible results. The farmer will still farm as his father did until he is compelled to do something his father never did—pay for the actual quantity of water he consumes. Not until then will he become an efficient agriculturist.

Many of the private irrigation projects are not built to be operated as irrigation enterprises, but merely as aids in the sale of lands. There are many such projects in existence to-day. The only thing that keeps the interest of the original investor alive is the fact that there are still lands and water rights unpaid for. His idea has been to build the project, sell his lands, collect his fees, and turn the operation of the project over to an organization of farmers. In this process he secures the services of engineers with the "construction lust" in their blood, and rarely is the facility of operation given a second thought. The result is a cumbersome system, without means of distributing water efficiently, with no provision for measuring the quantity consumed, or of detecting or preventing waste. In a short time the lower lands become water-logged and the alkalis are concentrated and brought to the surface. The next move is to install a drainage system, frequently at a cost per acre as great as the original irrigation system.

When the Sunnyside Canal was first constructed, the water-table in the lower lands was 50 ft. or more below the surface. At present the water stands within a few feet of the surface in the same places. The writer has seen several of the older orchards killed outright by alkali, and the trees cut for fire-wood. Large tracts which once grew excellent crops are now barren wastes of white alkali. The damages from the excessive use of water on this project would have paid for metering the water to every farm within the project, even if meters cost $1 000 each. It is believed, moreover, that much of this damage would have been saved had the water been metered successfully to each tract of land.

The country has been spending years in the construction of irrigation works. Before it, now, is the task of operating them. In this work there is as large a field for the "efficiency engineer" in agricultural sections as there is in the shops and industrial plants of the country.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1188

NOTES ON THE BAR HARBORS AT THE ENTRANCES TO COOS BAY, AND UMPQUA AND SIUSLAW RIVERS, OREGON.*

By Morton L. Tower, M. Am. Soc. C. E.

With Discussion by Messrs. Lewis M. Haupt, and Morton L. Tower.

When the improvement of harbor entrances on sand coasts are planned or are being discussed, attention is given to the effect of the scouring action of the ebb current, the littoral drift, or alongshore currents, the resultant sand movement, and the prevailing direction of the storm winds. The path of the flood-tide currents has seldom been mentioned as a controlling factor.

In this paper attention is called to the fact that these flood-tidal currents are an important factor, if not the main one, in causing troublesome shoals at harbor entrances. The writer does not intend to imply that the other elements are not to be studied, or are of no consideration, but, as they have been discussed at some length by advocates of different systems of jetties in papers† before this Society, he will confine his remarks to the action of the flood-tide and its effect

* Presented at the meeting of December 21st, 1910.

† "Jetty Harbors of the Pacific Coast," by Thomas W. Symons, Captain, Corps of Engrs., U. S. A., *Transactions*, Am. Soc. C. E., Vol. XXVIII, p. 155.

"Description of Coos Bay, Oregon, and the Improvement of its Entrance by the Government," by William W. Harts, M. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. XLVI, p. 482.

Papers on Harbors, Inter. Eng. Congress, *Transactions*, Am. Soc. C. E., Vol. LIV, Pt. A, p. 137.

at three harbors on the Oregon Coast, namely, Coos Bay, and the Umpqua and Siuslaw Rivers.

That portion of the Oregon Coast between Cape Arago on the south, and Heceta Head on the north (Fig. 6, Plate XLII), presents a stretch of sand nearly 50 miles in length. It is broken by the above-named harbors and by five creeks which drain lakes of considerable extent between the harbors.

Coos Bay is immediately north of Cape Arago, the harbor entrance being well protected by the cape from all storms from the south and southeast. The Umpqua River entrance is 25 miles north of Cape Arago, and that of the Siuslaw River is 7 miles southward from Heceta Head.

Cape Arago is a low flat cape extending about 4 miles beyond the general coast line above low water. Beyond low water the writer has traced the reefs about 8 miles, with depths on the bare rocks of 60 fathoms at the outer end. On either side of the reef there is a depth of 90 fathoms to sandy bottom. At the shore the rocks and reefs generally rise sheer from depths of from 40 to 60 ft. It is evident that no littoral drift of sand occurs to any great extent around this cape.

Heceta Head is a bold promontory extending only 1 or 2 miles beyond the coast line. The offshore slope is much less steep than at Arago, and the under-water reef is not so prominent, yet the bare rocks extend into general depths of 40 and 50 ft. To the north the coast line, for 15 miles to Cape Perpetua, is rockbound. It is evident that there is no chance of sand movement from the north.

Along the coast a marine growth is found on the sandy bottom of the ocean at depths of more than 50 ft. This growth consists of shell-fish and the lower orders of animal life on which fish feed; bottom fish of the sole, halibut, and skate species, are to be found on the sandy bottoms, although halibut generally feed close to the rocks. On sandy coasts, no marine growth, other than animal life possessing some means of accommodating itself to a changing bottom, appears inside the 40-ft. contour. A good illustration of this may be found in the fact that, on sandy bars, buoy chains and anchors do not accumulate barnacles where the chain lies on the sand in the shoal locations; while chains of outside buoys, generally placed in from 40 to 80 fathoms, accumulate growth for their entire length.

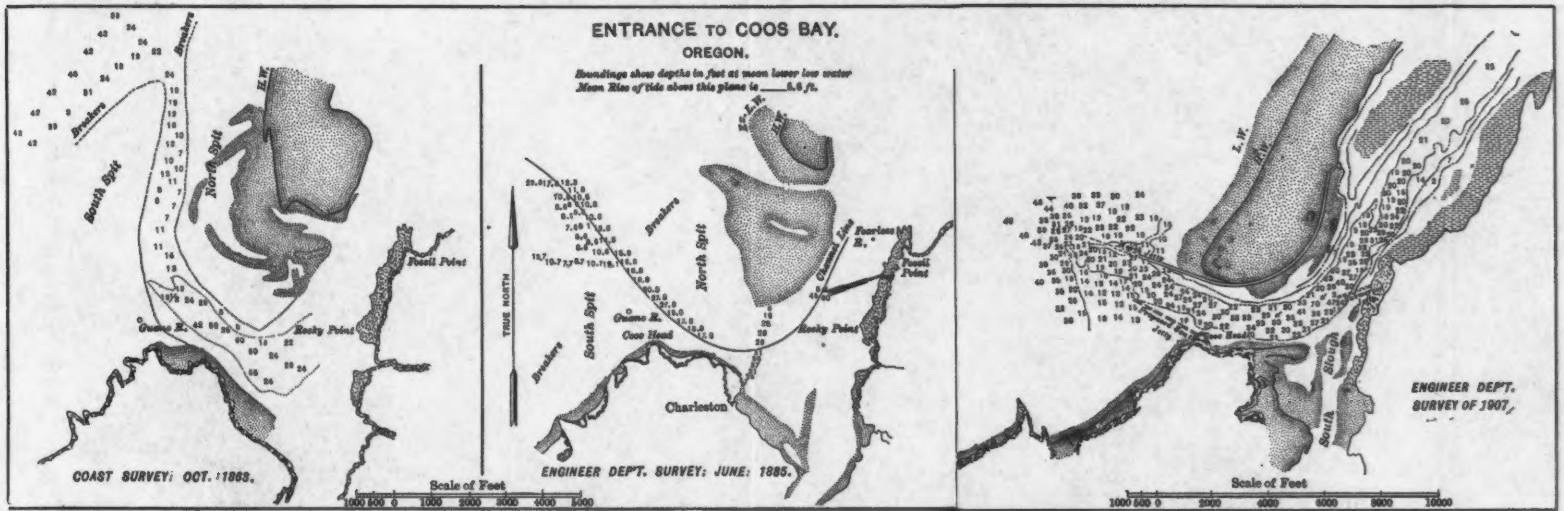


FIG. 1. FIG. 2. FIG. 3.

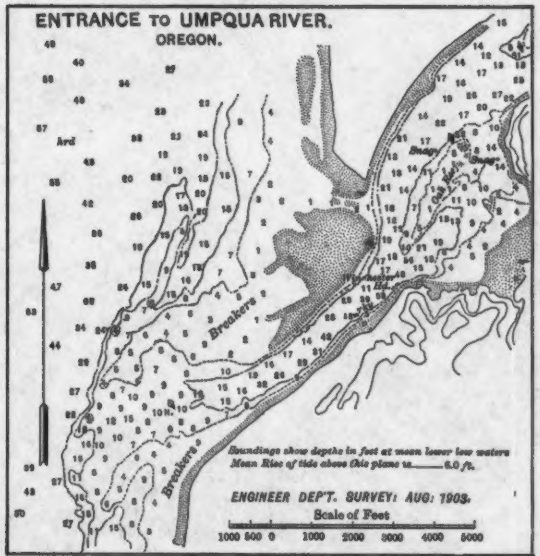


FIG. 4.

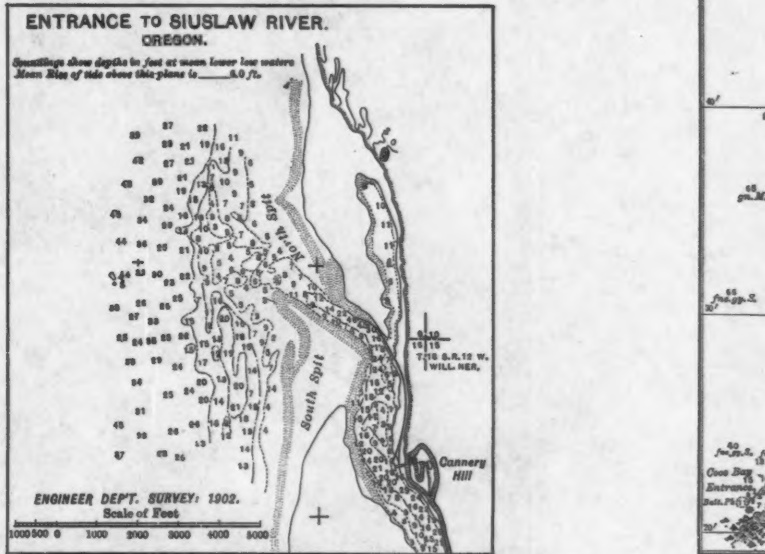


FIG. 5.

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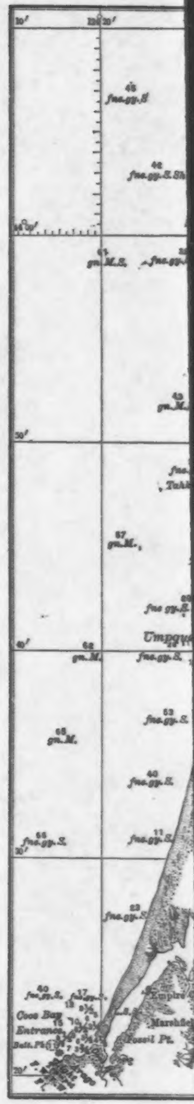

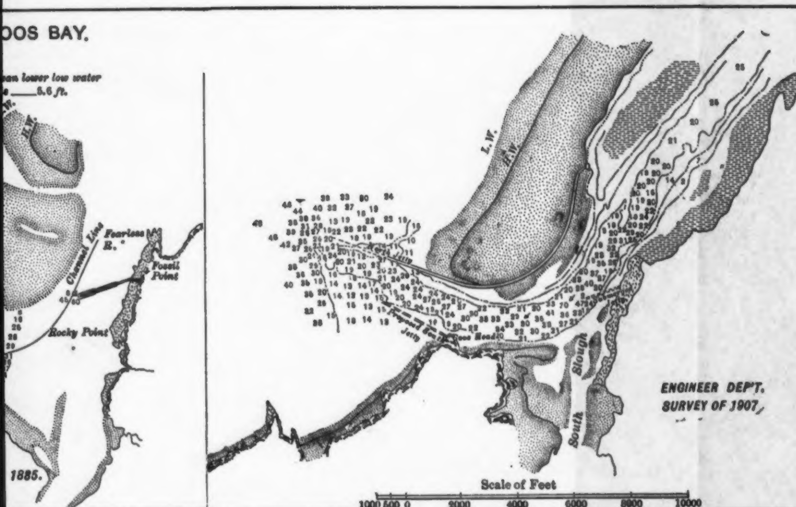
OOS BAY.
ean lower low water
e ___5.6 ft.
H.W.
Channel Line
Fearless R.
Fossil Point
Rocky Point
1885.
L.W.
H.W.
Jetty
Slough
South
ENGINEER DEP'T.
SURVEY OF 1907
Scale of Feet
1000 500 0 2000 4000 6000 8000 10000

FIG. 3.

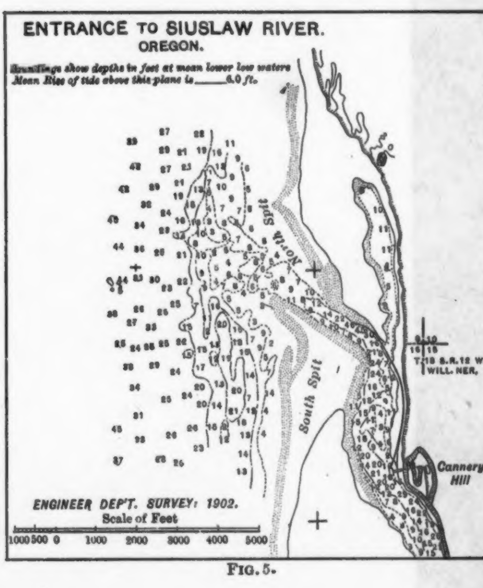
ENTRANCE TO SIUSLAW RIVER.
OREGON.
Soundings show depths in feet at mean lower low waters
Mean Rise of tide above this plane is ___6.0 ft.
North Spit
South Spit
T.18 S.R.12 W.
WILL. MER.
Cannery Hill
ENGINEER DEP'T. SURVEY: 1902.
Scale of Feet
1000 500 0 1000 2000 3000 4000 5000

FIG. 5.

PLATE XLII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXI, No. 1188.
TOWER ON
BAR HARBORS ON THE COAST OF OREGON.

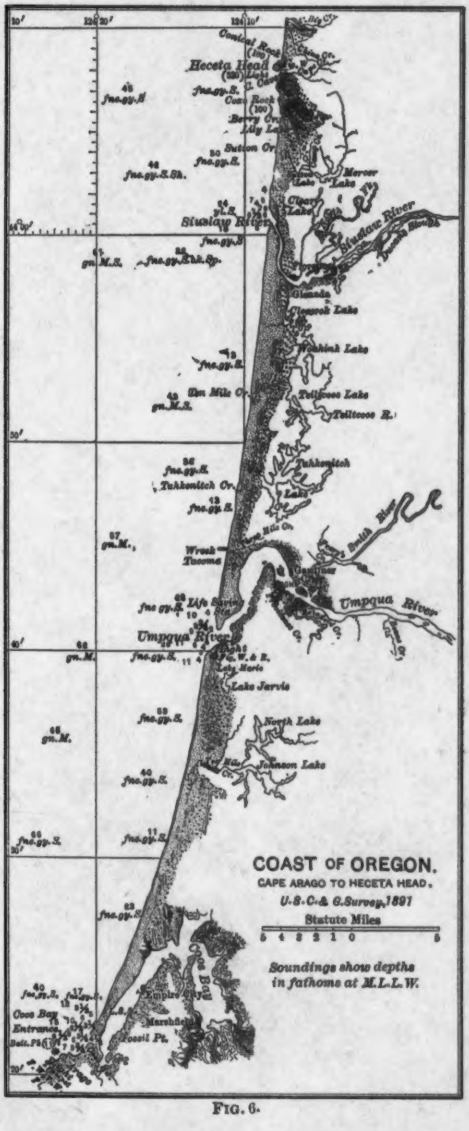

FIG. 6.

This evidence proves that the large movement of sand is confined to the shoaler depths of water between the 40-ft. contour and the shore. This is reasonable. The great factor in moving sand is the change in form of shoreward moving waves from what has been termed by Thomas Stevenson as oscillating waves to waves of translation. The change occurs when the under-water portion of a wave of oscillation encounters the bottom and is checked; the inertia of the upper portion carries the water on until the top of the wave falls over.

Waves of oscillation produce very little horizontal force, while the energy developed by waves of translation is enormous. It has been measured on the coast of England and has amounted to as much as 6 000 lb. per sq. ft. It is undoubtedly far more when the great waves of the North Pacific Ocean storms break on the coast. Under the influence of the waves, the sands on the beach are constantly undergoing change, thereby affecting its profile.

Long periods of quiet ocean without unusual storms produce a short beach, the sand being pushed shoreward; between the storm high water and low water a contour assumes many small irregularities. During periods of violent storms the beach is long, the contours are straight and parallel with the beach line, and the sands are beaten down until a wheeled vehicle scarcely leaves an imprint. These movements are local, however, and if there is a resultant movement of sand along the Oregon Coast, it is not apparent in the accumulation of sand at either end of the area between Heceta Head and Cape Arago. As far as the improvement of harbors for the benefit of the present civilization is concerned, the resultant littoral movement or the accumulation or disappearance of the sand are not factors of greatest importance.

The original source of this sand area is hard to name, and like other geological phenomena, is more or less a matter of theory; it may be the deposits from the Umpqua River, during the many geological ages that the land has been above the water. From the beach the sand stretches shoreward to 5 miles in the middle distance between the two capes. It is bare of vegetation, and near the timber line forms immense dunes, which reach elevations of 150 ft. Inside the timber line it underlies a stratum of from 4 to 8 ft. of soil under the forest. In the form of sandstone of varying degrees of hardness

it overlies the lignite and shale deposits of the southern end of the country, extending well into the western slope of the Coast Range.

Figs. 1 to 5, Plate XLII, show the outline of the shores at the three harbors, the under-water depths being expressed in feet. It will be noticed that in their unimproved state the shore lines were very similar. The entrances consisted of long curved channels having large areas of shoal water on one or both sides.

The entrance at Coos Bay is shown on Figs. 1 to 3, Plate XLII, and includes the harbor in 1863 before any improvement was undertaken, in 1885 before the north jetty was commenced, and in 1907, the latest available data. Fig. 4, Plate XLII, is a sketch of Umpqua River where no improvement has been undertaken, and Fig. 5, Plate XLII, is a sketch of Siuslaw River where a jetty has been started, but has not yet reached a sufficient length to create any improvement on the bar.

Coos Bay and Umpqua River have controlling natural headlands and reefs of sandstone on the south side of the channel to direct the current in the gorge or harbor throat. Siuslaw, however, has sandy shores on both sides of the entrance, the stiff clay bank underlying Cannery Hill being too far upstream to be a controlling factor at the bar. The present jetty would form a controlling reef and be a valuable aid to one on the south spit.

The currents at harbor entrances, which result from the rise and fall of the ocean with the tidal wave, are similar at all harbors. Beginning with high tide, the outgoing current commences about 30 min. after actual high water, the delay being due to the inertia of the moving water in the channels. At this time, and at low-water slack, the greatest slopes or differences in elevation between points inside and outside the harbor occur. The first currents occur generally along the shores or in secondary channels, and sometimes they last an hour or more before the change in the direction of the current in the main channel takes place. As the current gains headway, it tends to follow the path of the main channels through the harbor throat and to sea; if there are no obstructions, it flows out with unchanged direction. On reaching the sea, the current is checked by the waves and by the friction of the ocean water, and the suspended matter is deposited.

At the first of the flood-tide, the same delay in the main channel

currents occurs. The water rising along the shore, which, owing to the crescent shape of the bars, is a short distance from the inner harbor near the high-water line of the spit, pushes through the secondary channel which, in this vicinity, is generally found across the shoal.

The velocities across the shoal are considerable, and in the shallow water the sand agitated by the waves is carried along, and the water enters the harbor channel with a capacity load.

During the whole of the flood-tide, the flood current, owing to the influence of the shoreward moving waves and the short direct route, continues to push over the spits into the channel. During rough weather, when the violence of the waves disturbs greater quantities of sand, the proportion of water entering across the spits is greatly increased, and continues for a large portion of the ebb-tide as well, while the seas roll across the spits into the channels.

The inner or bay side of the spits, over which the flood currents enter the channel, will always be found to be steep, with a rolling slope of sand during flood-tide and a caving bank during the ebb current. The sand entering the channel is carried out through the harbor throat and again settles on the outer edge of the shoals, where the current is decreased on entering the ocean. In other words, the cycle is commenced again, and the great quantity of sand forming the bar is continually making round trips in over the spits with the flood-tides and out through the channel with the ebb currents. During storms the action is increased, as sand is stirred up to greater depths and carried shoreward with greater velocity.

The most effective place in which to control this movement is the shallowest portion of the cycle, or along the ridge of the shoal. This is always found on the convex bank and near the harbor channel. The danger to be provided against is the location of a jetty too close to the channel, where the structure would be undermined when the supply of sand from the ocean side was cut off. A generous allowance for flat slopes should be provided for on the channel side of the inner portion of the jetty. The jetty in the shoaler portions may be built of small stones and a thick brush mattress, depending on the accumulating sand to provide the real and permanent barrier. The jetty should be carried to high-water-crest height, and as the sand appears above that height, the available area should be planted with suitable vegeta-

tion. The decaying sea grass and driftwood will provide sufficient soil to maintain Holland or sand grass (*Arunda Arenaria*). The sand, caught and held by the grass, will continue the work above tide, and once out of the reach of the waves, the jetty is reasonably safe. In this way provision is made for the inner or easy end of the jetty. The outer end should extend into such depths that the sand will not pass around it in water of less depth than is expected to be maintained across the bar.

There will always be a bar or section with less water than is found in the gorge or harbor throat, unless expensive and continual dredging is resorted to, an expedient so costly as to be warranted only at the principal harbors of the world.

As an example of the difficulty that may be expected in maintaining a jetty in considerable depths, it may be stated that for 800 lin. ft. the outer end of the Coos Bay jetty was built three times to 24 ft. above low water and beaten down at the extreme end to 20 ft. below low water, or only a few feet above the surrounding sand. At the present time it slopes to just above low water in about 800 ft. from its outer end. This portion was built originally in from 20 to 24 ft. of water, at low water. The specifications for the stone used allowed one-fourth to be of pieces weighing from 400 lb. to 2 tons, one-half to be of pieces weighing from 2 to 4 tons, and one-fourth to be of pieces weighing more than 4 tons each. The largest pieces received weighed as much as 18 tons. The outer end of the jetty, as will be seen by reference to Plate XLII, is normal to the direction of the waves.

Referring again to the plans, Fig. 1, Plate XLII, shows the bar in its natural condition, before any work whatever was commenced. The entrance was well to the north, with a large area of shoal on both spits, and there was a narrow erratic channel, changing in depth and direction with each storm. The spits were very low, being exposed only at extreme low water, the waves carrying across the bay and breaking with great force on Rocky Point. At long intervals the channel would break out in a position near the present location, and better depths and a shorter shoal always resulted. This led to a desire to make the southward location permanent, and was the result expected from the original project for the jetty extending from Fossil Point to Coos Head, Fig. 2, Plate XLII. This project was adopted in 1879 and abandoned in 1889 when a new project, along the

lines of the more successful jetty built at Yaquina Bay, was adopted. At the time the first project for the Coos Bay jetty was commenced, the work of improvement at the harbors of the Great Lakes by jetties or sea-walls was in active progress under the direction of the United States Engineer Corps, and the same methods and styles of construction were used at Coos Bay, which was the first Pacific Coast harbor entrance for which Federal appropriations were made.

Shortly after commencing work at Coos Bay, appropriations were secured for the improvement of Yaquina Bay, and work was commenced there, a similar style of construction being proposed. As the Yaquina work was in a more exposed position, the method of construction was soon found to be inadequate, and the Assistant Engineer, James S. Polhemus, M. Am. Soc. C. E., proposed, and was directed by the Engineer Officer in charge of the work, to use the type of jetty now adopted at all harbor entrances along the Pacific Coast north of San Francisco.

There has been continual development in the methods and plant used for jetty construction, especially at the mouth of the Columbia River, where liberal appropriations and the magnitude of the work have allowed the building up of a splendid plant for carrying on the work. The construction of the jetty and the details of the plant used have been fully described by Major Hart.*

The original type of jetty built at Coos Bay under the first project consisted of large timber cribs, built cob-house style, of sawn 12 by 12-in. timbers bolted together. The cribs were placed in line, filled with small rock and sunk, and then rip-rap was dumped along the sides.

Owing to the rapid destruction of the timber by the teredo, as well as the expensive cribwork and the impossibility of placing the cribs in the more exposed positions later considered desirable for jetties, this type of construction has been finally abandoned on this Coast.

The construction of the inner jetty certainly produced results on the entrance to Coos Bay. The curve of the channel at the south end of the bay was eliminated. The height and width of the north spit were increased, and the position of the channel across the outer shoal

* *Transactions*, Am. Soc. C. E., Vol. XLVI, p. 482.

was held more permanently and farther south than the old channel. The depths were not much increased, and a well-developed flood-tide channel, several hundred feet wide, with a depth of 1 ft. at low water, was generally found just southward from the high-tide line of the north spit.

Through this channel the first of the flood-tide entering the bay carried large quantities of sand. The extreme end of the north spit was scoured off, but the persistent action of the flood-waters across the shoal caused the channel to narrow between the end of the jetty and the sand island, and great quantities of sand were constantly being carried in over the shoals and out through the channels, with resulting constant changes in the bar depth.

The first work on the later project was commenced in 1891. The jetty was extended to its projected length, 10 368 lin. ft., by August, 1894, and during 1895 the crest of the enrockment was brought to half-tide height. Between 1895 and 1900, $240 000 were spent, completing the jetty by increasing and maintaining the enrockment, in which about 300 000 tons of stone were placed. As before mentioned, at the extreme end of the jetty the enrockment was built three times to the height of the tramway rails, 24 ft. above low water, and was as many times beaten down by the sea to 20 ft. below low water at the extreme end.

Immediate results followed the building of the North Jetty. The large quantity of sand entering the bay across the spit was stopped, and it commenced to build up behind the jetty. The south spit and bar, not receiving its supply of sand with the ebb current, was scoured down and the channel held in permanent position. The sand on the inner side of the jetty, across the channel from the outer end of the old work, was washed away. The flood current, no longer able to crowd in on the north side, commenced to push in along the south side of the channel, resulting in the prominent shoal across the south arm of the harbor. This shoal is inside, and does not interfere with commerce. The area north of the jetty has continued to accumulate sand and extend seaward. It has been planted to Holland grass, which continues the accumulation of sand above high water. The first four years after the completion of the jetty across the north spit witnessed the best bar depths (22 ft. at mean lower low water) in the history of the port. The position of the channel was fixed and has so remained.

The depth has been reduced at times to 17 ft. at mean lower low water, but is generally 18 ft.

The present condition of the channel is shown by Fig. 3, Plate XLII, which is the latest authoritative map of the locality, with a least low-water depth of 19 ft. The last work of jetty construction at Coos Bay was done in 1901, since which time Holland grass has been planted, the jetty has been cared for, etc. The tramway has disappeared, and the outer end of the enrockment needs rebuilding. The sand washing past the end and over the lower portions of the rock is commencing to cause shoals, and undoubtedly more work will be required very soon. The 18-ft. low-water depth accommodates the port's commerce very comfortably. It is as great as is to be found in the channels of the inner harbor for any great distance, and, while more depth would be desirable, the maintenance of works, in order to secure it, would be very expensive. The project under which the North Jetty was constructed included a second jetty on the south side of the channel to produce a permanent depth of 18 ft. by scour.

The results obtained by the single jetty on the north side have maintained the projected depth so successfully that no expenditure for the South Jetty has been warranted. The total amount of money appropriated for the improvement of Coos Bay entrance has been \$938 750. It has been expended approximately as follows:

For the first project, adopted in 1879...........	\$213 750
" " second " " " 1889...........	675 000
Expended since closing of jetty work, for survey steamer, dredging, planting grass, etc., and on hand................................	50 000
Total................................	\$938 750

As a result of the improvement at Coos Bay, the freight rate to San Francisco compared with that from Umpqua River—a port of the same nature as Coos Bay before its improvement, and of similar depth —is 50 cents per 1 000 ft. of lumber in favor of the improved port.

The Umpqua River, Fig. 4, Plate XLII, is one of the largest streams of the Pacific Coast, draining an area of more than 4 800 sq. miles which has the proverbial rainfall of the "Webfoot State." Heading in the Cascade Range in areas of fine pine forests, it crosses

the drier valley between the Cascade and Coast Ranges, and breaks through the Coast Range in a narrow cañon, with a short narrow valley between the coast mountains and the ocean. One large tributary, Smith River, enters it from the north.

With all this splendid drainage area and immense flow, aided by the deflecting reefs near the harbor mouth, the river is unable to scour a desirable channel through the bar. The pressure of the sand washed in across the north spit holds the deep water hard against the rocks of the heads and reefs on the south side of the channel. At the Umpqua River entrance a jetty along the north spit, duplicating the single jetty at Coos Bay, would produce similar improvement, and could be economically constructed. Materials for construction are convenient and abundant on the Umpqua River, and a moderate improvement could be effected for a comparatively small expenditure.

At Siuslaw River, Fig. 5, Plate XLII, it will be noted that the entrance, while having all the characteristics of the other two harbors, is reversed, and the larger shoal area is on the south side of the channel. At this place a north jetty has been partly constructed by the Federal Government. The project was to create a depth through the shoal by scour.

The jetty was extended along the shore to a point opposite the inner edge of the break through the sands; then it curved outward, normal to the coast line. By the time the work was extended to the curve, the channel had moved northward, and, in 1897, the jetty was built entirely across the river, shutting it off. A narrow path was quickly cut around the end of the work, and, during the winter following 1897, a new channel broke out to the south in the desired location, and has not yet shifted to any great extent. The depth, however, is very unsatisfactory, as it does not permit the commerce to be handled economically.

Here, again, a jetty depending on scour alone has not been a success, and it has also been expensive to construct, owing to the scour and depth encountered at the end of the work while continually turning the channel. The project was finally abandoned by the General Government in 1902.

The port of Siuslaw, consisting of a legalized body representing the benefited property, has been organized under an act recently passed by the Oregon Legislature, has issued bonds, adopted a project, and

commenced the construction of a jetty on the south side of the entrance, the idea being to cut off the sand movement into the channel and thus give the ebb-scouring current a smaller task to perform. Work has now commenced, and the results will be interesting.

This paper could have been greatly enlarged, but the writer's idea has been to call attention to only one element of harbor bar formation. Other points and theories of sand movement, with a full description of the methods of construction, have been presented in the papers and discussions previously mentioned.

DISCUSSION

Mr. Haupt.

Lewis M. Haupt, M. Am. Soc. C. E. (by letter).—In this interesting paper Mr. Tower has added some material facts which emphasize the importance of a thorough consideration of all the forces which co-operate to effect changes at alluvial inlets, and directs attention to the influence of the flood-tidal currents as being an important factor, if not the main one, in causing troublesome shoals.

Lest too much stress be unduly laid on a single factor, it is well to note that the literature on this subject is prolix, and that many physical hydrographers and maritime engineers have directed specific attention to the influence of tidal currents and the paths which they take in approaching the tidal estuaries or any breach in the ocean littoral. Rear-Admiral Davis, in "The Law of Deposit of the Flood Tide: Its Dynamic Action and Office,"* Sir John Coode, on the "Chesil Banks," and Wheeler, Mitchell, Hilgard,† and many others have definitely directed attention to this factor, and the discussions are of great interest to the profession, because so much is involved in the cost of harbor bar improvements and their maintenance in a fixed position.

When the writer was stationed on the Texas Coast, in 1869, as the United States Engineer of the Fifth Military District, his attention was directed to the delays in crossing the bars and the necessity of lightering passengers and live stock off shore. This led him to devote his attention to these specific problems, with the result that he designed a system whereby a part of one jetty, properly placed, might control the resultant forces in such manner as to remove the bar automatically and create a self-maintaining channel, and Congress was so well satisfied with the merits and economies of this device, that in 1902 a test of its efficiency was ordered to be made at Aransas Pass, Texas, where all previous efforts had failed. After the removal of the former obstacles, and before the original design was completed in its entirety, the feeble 14-in. tide had scoured out the channel to depths of from 20 ft. to more than 26 ft., the original depth being from 5 to 8 ft., without any dredging whatever. This work was designed to control the sand driven on the bar by the "flood-component" of the external forces, and not primarily to concentrate the ebb, as was the prevailing custom, by two jetties, which merely prolong the slope, increase the friction, reduce the tidal ingress, and throttle the inlets so as to require frequent dredging to create and maintain the channel.

* Smithsonian Contributions, Vol. III, 1851, where "It was laid down as a fundamental principle, that the deposits on the ocean border are only made by the current of the flood tide." See also "Discussion on the Dynamic Action of the Ocean in Building Bars," by the writer, Am. Phil. Soc., March, 1889.

† Smithsonian Report, 1874, p. 219. Also letter to the writer, May 20th, 1880, stating "You are entirely correct, as it is the unceasing activity of the flood that produces the forms so characteristic of harbor entrances." See *ante*, Am. Phil. Soc., 1889.

Mr. Haupt.

In many cases the jetty may be detached from the shore and be placed so as merely to connect the deep water on the outer and inner slopes of the bar. It should lie between the proposed channel and the source of the resultant drift and be concave to the channel, thus creating a reaction which will effectually prevent the deposit of material on the protected portion of the bar.

The author calls attention to the danger of the structure being undermined if placed too near the channel, but at Aransas Pass this has been prevented by a suitable apron laid along the toe of the work, which has reduced its deterioration to only about 2 per cent.

This well-known and much-discussed case is cited as furnishing the best evidence of the importance of the questions raised by Mr. Tower, and as emphasizing the great economy which may be secured from an intelligent application of the available resources of Nature, particularly as the same site, subject to the same forces, furnishes an admirable illustration of the comparative results of the two systems, both before and after the reaction jetty was partly built. The previous work, after nearly 20 years, and at a cost of more than $500 000, was abandoned with "insignificant results."

The reaction jetty, only partly finished, produced immediate scour, and soon after the removal of the old, obstructing works, cut the 20-ft. channel through, without advancing the bar, at a less cost to the Government than the former work; and when it was decided to attempt to deepen the channel, in 1907, before it had reached a condition of equilibrium, by closing the tidal opening and building a second jetty, the channel shoaled to less than 14 ft. immediately. In consequence it has become necessary to approximate more than $3 000 000 in the effort to recover the depths by jetty extensions, dredging, and other works, and for the protection of the adjacent islands from erosion.

Had the general principles of the utilization of the littoral forces and the control of the bar-building drift been duly recognized when the South Pass was being opened, the late James B. Eads, M. Am. Soc. C. E., is reported to have said that he would not have built his west jetty, which has been largely buried under the deposits created by that on the east bank.

Incidentally, the closure of the Cumberland Sound, which required an emergency appropriation of $500 000 to remove a portion of the south jetty, and the effort to open a channel across the bar south of both jetties, might have been avoided, while the subsequent building up of the windward or north jetty at its outer end enabled the natural forces, aided by dredging, to restore a fairly good, normal channel.

The use of the two jetties at the Southwest Pass, aided by constant dredging and the extension of the bar far beyond the ends of the work, might have been saved by the judicious application of the same

Mr. Haupt. forces which had created an excellent channel in the Pass above with depths of from 40 to 100 ft., in a channel 1 300 ft. in width, without cost, and had also added some 150 sq. miles of rich, fast land to the territory of the State and Nation through crevasses now being closed.

The attempt to open a deep-water harbor at Cold Spring Inlet, N. J., by two jetties about 700 ft. apart and 1 mile long, which has resulted in a channel 6 ft. deep at mean low water, at a cost of more than $1 000 000, might have been saved. Many other instances of the practical application of the general principles enunciated in the paper might be cited, but these few should suffice to point the moral as to the great possibilities of securing better results at less cost and without artificial aid, by a recognition of the fact that sand is heavier than water, that the breakers are the most potent agencies in transporting it, and the flood-tide the great propelling force, while, when once deposited, a current unaccompanied by breakers is impotent to disturb it unless a reaction or eddy is set up by some resisting medium adjusted so as to cause erosion.

Furthermore, it would seem to be pertinent at this time to direct the attention of Members of this Society to the paramount importance of giving due weight to these dynamic forces, which are so vital in the restoration of our former commercial supremacy by re-opening the channels to the sea, to state that the plan now proposed for the creation and maintenance of the entrance to one of the greatest engineering enterprises on earth does not seem to have been adapted to protect the channel from the action of the off-shore forces. These must create an extensive shoaling directly across the path of navigation, and the extensive breakwaters will not prevent but rather augment it, requiring constant and expensive dredging to remove. This may be avoided in the first instance at much less cost.

Much might be added as to the cyclic movements of the ebb thalweg over the outer bars of entrances and the necessity of arresting the forces which produce them, that the location of the channel may be made permanent; but the whole problem has been presented so fully in previous discussions in the *Transactions* of the Society and elsewhere, that it will suffice to refer to them for further information.

Mr. Tower. MORTON L. TOWER, M. AM. SOC. C. E. (by letter).—In Mr. Haupt's kindly criticism, he says:

"In many cases the jetty may be detached from the shore and placed so as merely to connect the deep water on the outer and inner slopes of the bar."

Such an arrangement, with the tidal action common at all the Pacific Coast harbors, would invite the formation and maintainence of a distinctive flood-tide channel into the bay in the rear of the jetty.

Through such channels, the first of the flood-tide and wave-accelerated current in the shoal water would carry a large quantity of sand,

which would have to be disposed of in some manner, and, without the intervention of dredging in the lower harbor, would result in much the same action as naturally occurs at unimproved entrances, where such secondary channels are generally to be found. Mr. Tower.

Waves in shallow water disturb large quantities of sand. The same sand, once deposited, will resist considerable steady current. It is desirable, therefore, that the flood currents enter the harbor over a minimum of shoal sand bottom area.

In estimates for jetties on sand shores, provision should be made for a suitable apron protecting the toe of the enrockment, no matter how far located from existing channels, as the current, sooner or later, will seek the protecting wall for at least a portion of its length.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1189

TIMBER PRESERVATION, ITS DEVELOPMENT AND PRESENT SCOPE.*

By Walter Buehler, M. Am. Soc. C. E.

With Discussion by Messrs. Richard Lamb, J. Martin Schreiber, George W. Tillson, Ernest F. Hartmann, A. L. Dean, and Clifford Richardson.

Timber preservation has not been developed from any one process, but from many; it has included the elimination of those not bringing results, the retention and development of those showing results, and the addition of new processes.

The first authentic report on timber preservation was probably that of a Special Committee appointed by this Society in 1880, which report was published in 1885.† The Special Committee discussed the various processes in use at that time, in great detail, and prepared a number of tables showing the results obtained; and it is interesting to know that a great many of its conclusions are accepted to-day by those conversant with the subject.

The writer will not attempt to review in detail the development of all the processes in use in 1880, but will confine this paper to the two basic processes, namely, Burnettizing and Creosoting, as practically all those in use to-day are either the developed basic processes or modifications of them.

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* A table of standard practice for the preservation of timber for railroad ties and tie-plates, to accompany this paper, is filed in the Library of this Society.

* Presented at the meeting of December 21st, 1910.

† *Transactions*, Am. Soc. C. E., Vol. XIV, p. 247.

The Burnettizing process was patented by Burnett in 1838. The original mode of application was to steep the timber in an open tank. Burnett, however, soon adopted the "Bethell" method of placing it in closed retorts, thus forming a partial vacuum, in order to remove all the air and sap, and then injecting the liquid under pressure.

The Burnett process was introduced in the United States at Lowell, Mass., in 1850, and was there worked by the Bethell method until about 1862. It seems to have been quite generally used in the Fifties by a number of railroads, but with indifferent success. In fact, these failures caused its abandonment for a time and the substitution of the old "Kyan" process, or use of chloride of mercury.

The Special Committee, after a thorough investigation of these failures, reported as follows:

"1. Original imperfections in the 'Bethell' process. The partial vacuum did not properly clear the timber of sap. This has since been improved upon by previously steaming the timber, to liquefy and vaporize the sap, before the vacuum is applied.

"2. It was probably a mistake to select bridge timber for this experiment; imperfectly as the work was done, it would have proved a far greater success if it had been applied to cross-ties.

"3. Operating upon unseasoned timber. As practiced in Europe, Burnettizing is exclusively applied to seasoned timber. This being generally imported from a distance, has a chance to dry in transit; or if cut in the vicinity of the works, it is piled up for several months before treatment, or is thoroughly steamed, so that the water may evaporate and make room for the solution. Moreover, it is also well dried before using, to prevent the zinc from washing out. As a confirmation of this view, it may be mentioned that while the bridge timber did not last well, several sets of switch ties which had been cut about 8 months and seasoned, were Burnettized at Owego, for the road department of the Erie Railway, and laid in its tracks, with the result that nine years afterward they did not show a particle of decay. These ties have been lost sight of since, but your committee has in its possession an oak tie, one of a lot of two car loads, seasoned and Burnettized at Owego, which lay in the track at Susquehanna station for 17 years, and is almost perfectly sound to-day.

"4. Insufficient pressure. It has been suggested that the pressure ought to have been some 200 pounds per square inch and continued 8 hours, instead of 4. This might have produced somewhat better results, but it is believed that the last cause, which remains to be mentioned, more fully accounts for the partial want of success.

"5. Undue haste in treatment. In accordance with the usual railroad practice of never ordering materials until they are imperatively

required, the timber was not procured until the bridge which it was intended to rebuild was about ready to come down. Then there was great haste; the Burnettizing works were hurried up, and the timber went straight from the stump into the cylinder, and from that into the bridge, with very imperfect treatment. A pressure was applied to the operatives, instead of to the cylinder, and as a result the timber was 'put through,' without sufficient preparation, some of it hard frozen in winter.

* * * * * * *

"It has been found, however, both in this country and in Europe, that when zinc solutions are employed, weak enough not to injure the strength of the timber, they are likely to wash out under the action of rains and moisture, and to leave the timber unprotected. This is quite well shown by the ties on the Chicago, Rock Island and Pacific Railroad (Experiment No. 8), which are decayed and exfoliated on the outside."

The following is a summary of the various causes of failure, brought out by the Special Committee:

First.—Class of material treated.

Second.—Condition of seasoning.

Third.—Use immediately after treatment, instead of allowing timber to season.

Fourth.—Insufficient pressure.

Fifth.—Too much haste, and consequent poor work.

Sixth.—The leaching out of the salt.

It is along these lines that the Burnettizing process has been developed. Engineers to-day do not advocate the treatment of bridge timbers, nor, in fact, any timbers, with a solution of chloride of zinc, such treatment being confined principally to ties. The value of preliminary seasoning is realized, and at present few ties are treated without it. It is also known that, in order to obtain the best results, it is absolutely necessary to dry zinc-treated timber after treatment.

The writer agrees absolutely with the fifth cause for failure, as reported by the Special Committee, that is, "undue haste, and consequent poor work," which probably has had more to do with failures, then and now, than any other cause.

It is now realized that the sixth conclusion in the report of the Special Committee was correct, and, profiting by this knowledge, the Burnettizing method is not condemned, but its use has been restricted. At present only certain timbers are treated with zinc chloride, and

more care is exercised in the selection of the uses and localities for which it is recommended. The fact that zinc chloride is a good preservative and the cheapest, warrants its continued use, provided discretion is exercised. It would be as foolish to pay the additional cost for creosoting ties in arid countries, as it would be to try to economize by the use of zinc chloride in swampy countries.

The strength of the solution to be used was mentioned in the report of the Special Committee, and it was concluded that too great a strength caused timber to become brittle. This is true to-day, and a 5% solution is probably the strongest now in use.

The strengths of the solutions vary from 2 to 5%, depending on the character of the timber to be treated; naturally, the denser the timber, the denser the solution.

The Bethell process, or Creosoting, was invented and brought into use in 1838 by Mr. John Bethell, of England, and in his discussion of the paper by Mr. H. P. Burt, in 1853, he made the following remarks:*

"Experiment proved that Oil of Tar, or Creosote, was perhaps the most powerful coagulator of the albumen [of wood], whilst it, at the same time, furnished a water-proof covering for the fibre, and its antiseptic properties prevented putrefaction. If then the operation of injection was well performed, there was every reason to anticipate the perfect success of the system. He found that by forcing at least 7 lbs. of Creosote oil into each cubic foot of timber, the process was perfect. * * * For railway works 7 lbs. per cubic foot would suffice, but, for marine work, it was better not to have less than 10 lbs. per cubic foot.

"He was inclined to prefer the employment of porous timber; it absorbed the Creosote more readily—was more perfectly saturated—was cheaper in its first cost, and when properly prepared, would last longer than heart of oak or any other very solid timber. * * *

"The best timber for use was young, growing wood, thoroughly dried; if it was fresh cut, or had been floated, so as to saturate the pores with water, there was great difficulty in creosoting it. * * *

"Mr. Bethell had experienced so much difficulty in procuring a proper quality of oil of tar, that he was compelled to establish manufactories and to distil it, to suit his own purposes."

Speaking further of its use and success, the Special Committee reports† that:

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* *Minutes of Proceedings*, Inst. C. E., Vol. XII, p. 225; also in *Transactions*, Am. Soc. C. E., Vol. XIV, p. 265.

† *Transactions*, Am. Soc. C. E., Vol. XIV, p. 266.

"As a protection against marine worms (the *Teredo Navalis* and *Limnoria Terebrans*) creosote is the only known preservative, and if there be enough of it injected it is thoroughly efficient. All other substances which have been tried, have failed, but the success of creosote has been established by abundant evidence all the world over.

"The English have found 10 to 12 pounds to the cubic foot sufficient in their harbors. The Dutch and Belgian engineers use about the same. But the French, relying upon a series of very careful experiments, extending over a series of years, by Mr. A. Forestier, consider that about 19 pounds to the cubic foot is required in their harbors in order to be quite safe against the *teredo*. This latter quantity has been used in this country by Mr. J. W. Putman for piles exposed along the Gulf of Mexico, and it seems probable that the higher temperature of the sea water, and consequent greater activity of the *teredo* in the French and our own southern harbors, requires a more thorough impregnation with creosote than in the northerly waters to afford immunity.

"The conditions under which creosoting is done in England differ from those in this country in two important particulars:

"1. The English operate upon *seasoned* timber, which, as it is chiefly brought from the islands of the Baltic, from Norway, and from Sweden, generally reaches them some 5 or 6 months after it is cut, and frequently remains stacked up some months more after arrival before it is creosoted. All the English engineers specify that 'the timbers shall be thoroughly dry before being creosoted,' while in this country we have almost invariably operated upon freshly cut timber, full of sap.

"This has led to steaming the timber previous to its injection with creosote (as well as with the metallic salts), in order to vaporize the moisture and make room for the solution. There are several methods of effecting this steaming, covered by a number of patents more or less meritorious, but the committee has included them under the general head of steaming in describing some American experiments.

"It is understood that steaming is now also used abroad, particularly in Germany, even when seasoned timber is injected, it being considered a valuable improvement upon the original process of Mr. Bethell.

"2. Creosote is cheap and abundant in England, while it is comparatively scarce and dear in this country. This, together with the higher price of labor and the longer time required to operate upon freshly cut timber, has made creosoting so much more expensive here than in England that in a majority of cases calculation showed that it was cheaper to let the timber rot and to replace it than to go to the expense of preparing it against decay.

"This condition of affairs brought about a considerable number of

inventions and experiments to circumvent the foreign experience and to make a little creosote perform as much as a great deal. None of these can be said to have been successful, and it is one of the anomalies which at first much puzzled your committee that the record of creosoting experience in this country should chiefly consist of failures, while the process is a thorough success in England."

In this short comment on creosoting, the Special Committee has dealt with all questions of importance, namely:

The quantity of creosote;
The character of the creosote;
The kind of timber to be treated;
The conditions of timber best for treatment;
The best method of seasoning the timber efficiently.

It is by reason of a better understanding of these questions that the art of creosoting has developed. Differences of opinion will be found on all these matters, but nevertheless the art, as a whole, has progressed.

Timber must be protected against decay, attacks of land and water insects, and, for some uses, it must be water-proof. In order to answer properly any of these questions, one must have a thorough understanding of decay, of the characteristics of the insects to be guarded against, of the timber itself, and of the preservative.

In order to answer properly the question in regard to the quantity of creosote to be used, it is necessary to know whether the timber is to be preserved against decay, against mechanical destruction by insects, or whether it is to be water-proofed.

If it is to be protected against decay, the locality in which it is to be used must be known, as well as the climatic conditions.

If timber is to be protected against marine insects, it is necessary to know whether it is to be used in Southern or Northern waters.

If it is to be water-proofed, it is necessary to know for what uses it is intended, and its characteristics.

The cause of decay is now generally understood, and the proper quantity of creosote necessary for its prevention is receiving considerable attention. Owing to the increased cost of creosote oil, and its comparative scarcity in the United States, processes have been developed, in the past few years, in which small quantities of oil are used, which it is claimed will produce the same results as the larger quantities used in the past.

These processes are now commonly known as the empty-cell processes. The older process is known as the full-cell process, and its advocates claim that in order to preserve timber effectually, it is necessary to use enough creosote to fill the cell structures. They also claim that the desire to reduce the cost of preserved timber by the use of smaller quantities of oil, has produced certain patented processes, the claims for which cannot be fulfilled.

Advocates of the empty-cell process claim that it is only necessary to paint the cell walls to prevent decay, and that, by their special process, it is possible to fill the cell structure completely with oil, and then withdraw most of it. Thus the cell structure is virtually painted with a small quantity of oil.

It is not the writer's intention to go into this controversy, and he will only state that it is known that timber can be preserved by the full-cell process.

All the information we have to-day, as to the value of creosote as a preservative, is based on the resistance to decay of timbers which have been treated by the full-cell process, and whether it will be possible to reduce the cost by the use of smaller quantities of oil, is still an open question. It will only be answered when sufficient time has elapsed to demonstrate thoroughly its efficiency by actual experience. It is to be hoped, however, that this endeavor to reduce the cost of preserving timber, will not lead to false economies and, consequently, to false impressions of a good preservative.

In the protection of timber against marine insects in Southern waters, present experience would indicate the use of at least from 18 to 20 lb., and, in some timbers, as much as 26 lb. of creosote oil per cu. ft. If the timber is to be used in Northern waters, from 10 to 16 lb. per cu. ft. is advocated, depending on the character of the timber to be treated.

There are certain purposes for which timber is used to-day, such as the modern wood block pavement, in which that quality which makes creosote a good preservative is of less importance than that which makes it a good water-proofing material.

When creosote was first used in the United States to preserve timber for paving purposes, it was thought that it was only necessary to prevent decay, and specifications were based on experience with creosote in preserving timbers for ties and other purposes. These

specifications naturally called for an oil similar to that which had been most effective in such preservation. It was soon found, however. that something more than a preservative was necessary. The timbers absorbed large quantities of water, expanded greatly, and destroyed the surface of the roadway. The natural development was to increase the quantity of oil used; this eliminated the trouble for a number of years, but it was discovered that in a short time the oil disappeared from the timber, absorption again took place, and trouble from expansion and contraction necessarily followed. This led to a study of the creosote itself, not only as a preservative for paving blocks, but also for timber, for it was naturally thought that if it disappeared from paving blocks, it would also disappear from timber. This deeper study into the preservative itself has developed it considerably.

It is now customary to differentiate the oils into those suitable for the preservation of timber, for paving blocks, and, possibly, for the protection of timbers against marine insects.

It is now generally conceded that the higher boiling constituents of the oil are the valuable ones, and whereas formerly high percentages of tar acids and naphthalene were specified, it is now customary to require low percentages of both. In fact, although early specifications called for not less than 10% tar acids and 40% naphthalene, those of to-day demand not more than 5% of the former and 25% of the latter.

When this oil is to be used for the treatment of paving blocks, the allowable tar acids are cut down to 1 or 2%, and the naphthalene to 10 or 12%, but where the timber is to be protected against marine insects, it is still customary to use oils with large percentages of naphthalene, for experience seems to prove that the best protection is afforded by oils of lower gravity.

Due to the development of creosote oil and its increase in gravity and viscosity, another question of importance was presented to the wood preserver, namely, the characteristics of the timber itself.

It was discovered that oils would penetrate certain timbers more easily than others, thus the timbers could be classified, those in each group having about the same factor of absorption.

Mr. F. J. Angier, Superintendent of Timber Preservation, of the Chicago, Burlington, and Quincy Railroad, who has made a thorough

study of this particular question, divides the timber into three groups, which he classes, *A, B,* and *C:*

Class *A* absorbing less than 22% in volume;
" *B* " between 23 and 30%;
" *C* " more than 30 per cent.

In Class *A,* he places such woods as red oak, pin oak, beech, and tamarac; in Class *B,* sweet gum, chestnut, sycamore, and poplar; and in Class *C,* tupelo gum, short-leaf pine, cypress, birch, and cottonwood.

Another classification which must be made is that of seasoned and green timbers. There seems to be no difference of opinion, at the present time, as to the fact that it is best, in all cases, to air-season timber before treatment; but conditions are such that this is not always possible, especially in the case of structural timbers. Almost all railroad ties in use to-day are being air-seasoned before treatment, but practically no bridge or structural timbers, and conditions are such that probably it will never be possible to air-season such timbers. Necessarily, then, some method must be devised to season them artificially. The writer will not attempt to go into the details of all the various methods in use to-day. Investigation has shown that, if timber is to be treated with an oil, it should be seasoned in oil, and if it is to be treated by a water solution, it should be seasoned in a bath of steam, precaution being taken not to steam it at too high a pressure, nor for too long a period, as excessive steaming materially reduces its strength.

The writer has attempted to bring out the important lines along which the art of timber preservation has developed, and it will be noted that this development has been practically that of the original basic processes, namely, Burnettizing and Creosoting.

Another development, which he wishes to review briefly, is that of the modified basic processes which are, with one exception, a combination of creosote and zinc chloride. The exception is the "Wellhouse" process, which is a combination of zinc chloride, tannin, and glue.

There are three processes which use a mixture of zinc chloride and creosote as a preservative, namely, the Rutgers, Allerdyce, and Card processes.

In the "Rutgers" process these two liquids are injected in a mixed

condition, the object being to maintain a uniform mixture by regulating the gravities of the two liquids so that one will remain practically suspended in the other. This method, while still in use to some extent abroad, has had very little success in the United States, and the writer knows of no plant now operating under this process.

The "Allerdyce" is a two-action process, the zinc chloride being injected first, and then the creosote oil.

In the "Card" process, which is practically new, having only been patented in March, 1906, the creosote is injected, mixed with the zinc chloride, the mixture being maintained under pressure by a centrifugal pump. This, of course, has the advantage over the Allerdyce process by reason of its being a one-movement process and, in addition, the oil is probably carried farther into the wood and is more evenly distributed.

These processes, undoubtedly, have considerable merit, and will prove successful, providing the zinc chloride penetrates to the heart of the timber and the creosote sufficiently to act as a plug to prevent it from leaching out.

The heart wood of certain timbers seems to resist penetration by creosote alone, although it is susceptible of penetration by zinc chloride. The main objection to the injection of zinc chloride alone, is, as stated before, that the uses of timbers so treated are restricted, due to the fact that the zinc, being a soluble salt, soon leaches out. This objection is overcome if the leaching can be prevented, and to do this the creosote oil is injected.

There seems to be little question that this process is of more value than straight Burnettizing, but it is never claimed that it is as effective as straight creosoting. Its cost is slightly more than Burnettizing and slightly less than creosoting. For the preservation of railroad ties in properly selected territories, it is undoubtedly of great value.

In this paper the writer has endeavored to give a brief history of the development of wood preservation. He has abstained entirely from the use of figures in showing this development, and has attempted to bring out only those phases of the question which to him seemed to be important.

DISCUSSION

Mr. Lamb.

RICHARD LAMB, M. AM. SOC. C. E.—There has been no improvement in materials or processes for timber preservation since the Special Committee on Wood Preservation, of this Society, reported in 1885. Inventors and merchants have patented so-called improvements on the Burnettizing or zinc-chloride process, the Kyanizing or bichloride of mercury process, the Thilmany or sulphate of copper process, and the Bethell or creosote in hermetically-sealed cylinder process. To an engineer familiar with the business of wood preservation, these so-called new processes seem to have been designed mainly for promotion purposes, to secure a trade advantage rather than additional efficiency, or additional economy without loss of efficiency.

With the exception of the business of treating wood blocks for paving, none of the new materials in combination with the tried ones, has made any considerable headway. It will be conceded that the Bethell process, or creosote in hermetically-sealed cylinders, has exceeded all others in general use for preserving wood against all causes of deterioration. It stands alone for use in preserving piles against the ravages of the *Teredo Navalis*. Opinion has not changed as regards the need of naphthalene in the creosote oil for this purpose, that attribute being the main stable germicidal agent of creosote oil.

The Burnettizing or zinc-chloride process is still used to a considerable extent for railroad ties where the roadbed can be kept comparatively dry. This process is cheaper than creosote, and quite effective, but the zinc chloride washes out of the wood in wet locations. Engineers who are advocating preservatives which contain no antiseptics or poisons should note that zinc chloride, bichloride of mercury, and sulphate of copper depend solely on poison to preserve the wood. Tar acids and naphthalene are the only poisons in dead oil of coal-tar. To leave out these fractions from creosote would be to abandon the only known method of preserving wood, namely, poisoning the bacteria of decay. In a paper on the preservation of ties, before the New York Railroad Club,* the speaker showed that creosoted ties pay for themselves every 15 years.

Since the presentation of the report of the Special Committee of this Society, creosoted conduits which had been in use 21 years have been taken up and proved to possess 100% salvage value; a number of these conduits have been relaid.

There no longer remains a question as to the feasibility or advisability of preserving wood. There is much talk in the United States now about the need of the conservation of the forest supply. This can best be accomplished by treating or preserving the wood after it is cut, so that a less quantity will be needed to meet our require-

* *Proceedings*, New York Railroad Club, February 18th, 1910.

ments. Woods which without treatment would decay too quickly to be of commerical value become valuable when preserved, and engineers should study well this phase of the subject. Mr. Lamb.

The conservation which should be sought now is that of the waste from the vast number of coke ovens in the United States. We import 38 640 000 gal. of creosote oil per year for wood preserving, only getting 17 360 000 gal. from home sources. In Europe they apply condensing apparatus to coke ovens, by which waste products heretofore lost are liquefied, producing a creosote like the distillate of coal-tar procured in America from gas-houses using coal. Much of this creosote is shipped to the United States.

In order to determine the best attributes of coal-tar for preserving, the speaker knows of no surer method than to take samples of treated wood of known history and make analyses by fractional distillation of the oil remaining in the wood. This has been done by the United States Forestry Department, and the results are recorded in Circular No. 98.

The averages in Table 1 have been compiled from the Government analyses of all tests.

TABLE 1.

Samples.	No. of samples.	No. of years in service.	Creosote, in pounds per cubic foot.	Percentage, Distillation of Extracted Oil.				
				205° to 245°	245° to 270°	270° to 320°	320° to 420°	Residue above 420°
Cross-ties	20	21.08	9.50	9.65	13.77	24.	24.69	22.46
Piles	12	32.	12.39	20.59	15.53	19.77	18.82	22.48
Paving blocks	5	20.6	13.77	20.92	22.96	23.32	16.56	15.58

The following are the usually accepted fractions for the degrees of heat, centigrade, as recorded:

Light naphtha, up to	110°
Light oil, } commonly called tar acids	110° to 170°
Carbolic oils, } commonly called tar acids	170° to 225°
Creosote oils	225° to 270°
Anthracene oils	270° to 360°
Tar or pitch	above 360°

The Government officials, however, have selected an arbitrary division for their fractions, as recorded in Table 1. However, by applying the foregoing commonly-used divisions, an idea of the nature of the various fractions can be secured.

The tests showed that piles which endured had been preserved by an oil which left in the wood an average of nearly 26% of naphthalene, and one sample showed 48 per cent. They all also had a good per-

Mr. Lamb. centage of anthracene, which is undoubtedly of equal importance with naphthalene as a preservative.

The results of tests also showed that from 10 to 12 lb. of creosote per cu. ft. is ample for railroad ties, and that from 10 to 20 lb. is needed for piles, depending on whether they are used in the warm waters of the South, where the *teredo* is more destructive, or in the colder waters of the North, where the season of their boring is shorter. Naphthalene and anthracene fractions predominated.

The average quantity of creosote taken from paving blocks which had been in use 20, 29, and 34 years, was 16.14 lb. The naphthalene and anthracene percentages were conspicuously large.

Tar acids or volatile oils are strong antiseptics. Although their stay in the wood is comparatively short, they exert an antiseptic influence on the bacteria of decomposition, and render a valuable service thereby. The speaker is convinced, however, that we have all the antiseptics needed in the naphthalene and anthracene which remain in the wood, and that not more than 1.5% of tar acids should be admitted in the creosote oil used for wood preservation.

While it is important not to accept any oils distilling below 150° cent., in order to avoid the carbolic or tar oils, which evaporate from the wood, it is equally important that no product of distillation should be accepted above 360° cent. This product represents simply pitch, which has no antiseptic qualities or ability to preserve the wood, other than to caulk the pores. This pitch is practically the same as that in heart pine, and will not preserve the wood longer than the natural pitch, so far as it acts as a germicidal agent. It requires high heat to keep it sufficiently liquid to enable it to be injected into the pores of the wood. This heat breaks down the fiber tissues, and takes the life out of the wood. Persons familiar with kiln-drying timber know that if it is dried at 280° Fahr., it becomes too brittle to dress. Where blocks have been treated with pitch, or oil of high specific gravity, say, 1.10 or 1.12, and laid in places where the foundations were not solid or the blocks not rigidly held, as in the case of a certain bridge in Brooklyn, and the floors on the ferry-boats of the Central Railroad of New Jersey, the blocks will be found to be split almost into splinters. In a bridge in Baltimore, in which the conditions were similar to those in the bridge just referred to, blocks of short-leaf pine treated with regular creosote oil were laid 6 years ago, and are as good to-day as when laid, in spite of the very heavy traffic which it has carried. Regular creosote oil, having a specific gravity of from 1.03 to 1.07, was used in treating those blocks, therefore no excessive heat was necessary to inject it, and the wood remained intact as to its fiber adhesion, no blocks having split.

It is contended by many engineers that this pitch or oil of 1.10 specific gravity is preferable in the case of paving blocks, because

it prevents the absorption of water. The sole purposes of stopping the absorption of water are: to prevent the alternate wetting and drying (which is a primary cause of decay) and the expansion of the blocks (which causes the buckling of the pavement). As a matter of fact, this heavy oil does not penetrate the blocks as thoroughly as the lighter creosote oil, and when they are split for closure-blocks it causes the exposure of the interior where the moisture can enter the wood. However, if creosote oil will preserve the wood, it is idle to contend that the pitch is better as a preservative, because it will caulk the wood better than creosote oil. If a paving block treated with 20 lb. of pitch per cu. ft. is dried, using 100° heat for 24 hours, and is then immersed in water, it will not absorb more than $3\frac{1}{2}\%$ by weight. Creosote oil having a specific gravity ranging from 1.03 to 1.07 will absorb about 4 or $4\frac{1}{2}$ per cent. The latter, however, penetrates the wood more thoroughly, coating the fiber, which is the part that absorbs the water when the swelling of the wood takes place. Mr. Lamb.

The Lowny process is based on the principle that it is not necessary for the oil to remain in the wood after it has coated all the pores thoroughly, and means are provided for extracting the oil after it has been injected. Although the speaker does not believe that this patented process will have very extended use, because it is objectionable to dilute the oil with the sap and steam and then use it over again; yet the principle is based on reasonable grounds, for experience has proven that after a few years' use one never finds in the wood the same amount of oil as was injected into it, and still its life is extended without appreciable deterioration.

In regard to the buckling of wood blocks, the speaker's observation has shown that when they are treated with the real creosote oil, this does not occur. He has never seen nor heard of the buckling of any properly creosoted wood blocks. On the other hand, in a large number of cases, he has seen serious buckling with blocks treated with pitch of 1.12 specific gravity.

The kinds of creosote are dependent on the sources of supply, which may be named as follows:

(1) Wood creosote oil,
(2) By-product coke-oven distillate,
(3) Water-gas tar distillate,
(4) Coke-oven distillate, and
(5) Coal-gas tar distillate.

These are numbered in the order of their value as sources for getting the oil containing the best constituents for wood preserving, as determined from the results of tests of woods treated, compared with the length of time they would have lasted without treating.

Mr. Lamb. The speaker was associated with the Carolina Oil and Creosote Company, probably the largest plant ever built for distilling wood for wood creosote oil and preserving timber therewith. Time showed that this oil could not be depended on for protection, either against the *teredo* or decay, and the process was abandoned.

Of late years by-product ovens have been perfected, and the Otto-Hoffman process has been established in America to make various products from the distillation of coal, but because of the high cost of the plants, its general introduction has been slow.

These by-product plants make coke, illuminating gas, sulphate of ammonia, and by-products of coal-tar. The residuum, after the foregoing valuable products have been extracted, is pitch of 1.12 specific gravity, containing but little naphthalene and anthracene. This pitch is used for roofing and water-proofing, and one company, with its allied interests, as far as can be ascertained, has bought up all the output that can be used for wood-block paving.

A committee of the American Society of Municipal Improvements recently reported that an oil of at least 1.10 specific gravity, at a temperature of 38° cent., should be used for preserving paving blocks; and stated that its investigations had shown that this oil is not controlled by one company.

One of the large creosoting companies manufacturing paving blocks wrote to each member of that Committee, stating that for some time this country, as well as foreign countries, had been canvassed for a delivery of 100 000 gal. of this oil, and it was found that it could not be obtained. Each member was asked to forward the names of companies in this country, in Canada, or other foreign countries, which manufacture this oil, and have the capacity to furnish it in large quantities—from 50 000 to 200 000 gal.—in a reasonable length of time after the order is placed. The answer to this letter, signed by the Committee, states in part:

"We might say, to start with, that the assertion in the report of the committee of the American Society of Municipal Improvements on the subject of Wood Block Paving Specifications that 'investigation on our part had shown that the oil recommended was not controlled by one company' was made in reference to wood block manufacturers only, and did not relate to oil manufacturers."

The only company mentioned which could furnish the oil is the one which controls the output of the 1.10 specific gravity oil. This company furnishes the 1.03 specific gravity oil to the creosoting company referred to, but has always refused to furnish the 1.10 specific gravity oil.

The chairman of the Committee wrote that a letter just received from Dr. Gellert Alleman, Professor of Chemistry, Swarthmore College, states:

Mr. Lamb.

"I have no hesitation in stating that any dealer in tar can fulfill the specifications to which you refer by either filtering the tar and adding a certain proportion of creosote oil to it, or in some cases by adding creosote oil to the unfiltered tar."

Attention is drawn to the speaker's remarks* on this phase of the subject in his discussion on Chicago paving practice.

One member of the Committee wrote:

"I have delayed answering your letter for the reason that the question of the limiting value of the specific gravity of creosote oil was referred to the Chairman of this Committee, and I, personally, did not look into this subject. Furthermore, the time allowed this Committee for the preparation of a report did not permit of an investigation into this subject by each of the members of this Committee."

The speaker has no doubt of the good faith of this Committee, and in view of the fact that the combination of wood-block manufacturers who can command that special oil has done practically all the wood-block paving propagation during the past few years, the members of the Committee, as well as many of the best engineers, have been misled in this important engineering business.

The specifications of this Committee require that the distillate shall not exceed 2% up to 150° cent., and shall not exceed 35% up to 315° cent. This is strictly a call for the by-product pitch, and is a bid for an oil which can be absolutely void of naphthalene and anthracene, the materials which engineers have depended on thus far to preserve the wood. It is begging the question to say that the kind of oil is immaterial, because it is expected that the pavements will be replaced before they would naturally have time to rot. If this is so, why specify other than an oil that experience has shown will preserve wood, unless it is a question of cost? As a matter of fact, although creosote costs more than pitch, when the Bridge Department of the City of New York specified for the Manhattan Bridge the regular blocks treated with creosote oil, there was a very material drop in the cost of the pavement under that of former orders when the 1.12 specific gravity oil was specified. Richmond is the only Borough of New York City in which regular creosote oil is specified. Learn what drop in prices there was when the specifications were changed from 1.12 specific gravity oil to regular creosote oil blocks, and compare the higher prices for similar work done in the other Boroughs, which call for the heavier oil.

Water-gas tar or pitch is as good as the by-product oil; in fact, it is very similar. It is more plentiful; any one can buy it. In a valuable paper by Charles N. Forrest, Assoc. M. Am. Soc. C. E., on "Preservatives for Wood Paving Blocks,"† by-product tar and water-gas tar are compared. He states:

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* *Transactions*, Am. Soc. C. E., Vol. LXVI, pp. 43-48.

† *The Engineering Record*, April 16th, 1910.

Mr. Lamb. "From the data already presented there appears to be no reason why coal-tar should be better than water-gas tar for the preservative treatment of wood paving blocks, but the following comparison of creosote oil distilled from water-gas tar with creosote oil distilled from coal-tar will undoubtedly be of interest to engineers who are interested in the preservative, aside from the water-proofing, features of this tar."

The following is the comparison of coal-tar creosote and refined water-gas tar referred to:

	Coal-tar creosote.	Refined water-gas tar.
(1) Original specific gravity at 15° cent.....	1.04	1.14
(2) Fraction distilling below 315° cent......	84.8%	16.00%
(3) Fraction distilling above 315° cent.......	13.8%	54.3%
(4) Total distilling from oil................	98.6%	70.3%
(5) Coke remaining in retort...............	1.4%	29.7%

The comparison of the three oils is as follows:

	Creosote oil.	Coal-tar called creosote.	Water-gas tar.
(1)	1.04	1.122	1.14
(2)	84.8%	34.2%	16.0%
(3)	13.8%	41.8%	54.3%
(4)	98.6%	76.0%	70.3%
(5)	1.4%	24.0%	29.3%

In buying creosote oil for wood preservation, we seek to purchase oils containing as little coke as possible. Note the above percentages of coke. The fractions distilling below 315° are naphthalene and anthracene.

In view of the past failures of water-gas tar as a wood preservative, the question is: What engineer wishes to specify that oil, or what company wishes to guarantee it? If it is a hazard to use water-gas tar, why is it not also a hazard to use by-product tar, which is practically the same? If specifications did not demand that the oil shall be the product of coal, either oil could be used under the specifications.

This Society should appoint a Special Committee to investigate this subject thoroughly and independently, and compile specifications strictly from an engineering standpoint.

The American Railway Engineering and Maintenance-of-Way Association adopted specifications for creosoting, demanding the best obtainable grade of coal-tar creosote—the pure product of coal-tar distillation, free from admixture of oils or other tars. It requires that the creosote shall have a specific gravity of at least 1.03 at 38° cent.

The speaker believes that the most desirable specification for creosote for all wood preservative purposes is as follows: Mr. Lamb.

The creosote shall be not less than 1.03 specific gravity at 38° Fahr., and not more than 1.07 specific gravity, the latter in order to insure thorough penetration. A fractional distillation, using 100 grammes of creosote, shall show percentages of dry oil by weight about as follows:

Up to 150° cent. (302° Fahr.), no distillate.

Between 150° cent. (302° Fahr.) and 170° cent. (338° Fahr.), not to exceed 1.5%.

Between 170° cent. (338° Fahr.) and 235° cent. (455° Fahr.), not to exceed 35%.

Between 235° cent. (455° Fahr.) and 300° cent. (572° Fahr.), not to exceed 35%.

The residue should be soft. The oil should contain not less than 25% naphthalene and at least 15% anthracene oils. Of the creosote oil, 95% should be soluble in carbon bisulphide, and equally in absolute alcohol. This test is to determine the amount of coke.

The above specification would have met the requirements for a creosote as good as any used in the tests as reported in the Government circular previously referred to.

If a specification for creosote was standardized by this Society, the coal-gas manufacturers would make their creosote conform to it with sufficient closeness, and the many bee-hive coke oven operators could be induced to distill their waste product for this specific oil. As it is now, many specifications are demanded, and there is no assurance that any one formula of oil a company might produce would command a market.

It is a fact that neither the by-product oil nor the gas-tar oil has been tried for wood block paving for a longer time than good heart pine will last. Heart pine blocks have always been specified when by-product oil has been called for. If real creosote is used, short-leaf pine can be specified, at a saving in cost for the wood of at least 15 cents per sq. yd. for blocks 3½ in. deep.

Nelson P. Lewis, M. Am. Soc. C. E., in a valuable pamphlet, has given an account of the European practice in wood block pavement, in which he shows that European nations have found the softer woods more durable than the harder ones. Baltic pine, which is like our short-leaf pine, is generally used abroad.

Data concerning wood block pavements have been collected recently by the American Society of Municipal Improvements, from the engineers of a number of American cities. Under the caption, "What Wood is Preferred," Boston, Mass., reported: "Short-leaf pine. Also long-leaf." Boston was the first city in the Eastern States to take up

Mr. Lamb. modern wood block paving, all the first blocks being made from long-leaf pine, as nearly all heart as could be secured. It is interesting to note that the engineers of that city are among the first in America to decide that short-leaf pine would be preferable.

The speaker has endeavored to show that pitch oils as wood preservatives can only be considered as experimental. In spite of this fact, the engineers of America are laying hundreds of thousands of dollars' worth of wood block pavements yearly, specifying blocks treated with that material, when they have the experience of Europe, California, and Texas to teach them that in those places regular creosote oil has satisfactorily preserved paving blocks for more than a quarter of a century.

Mr. Schreiber. J. Martin Schreiber, M. Am. Soc. C. E. (by letter).—Mr. Buehler's paper is a conservative résumé of the more important requirements of modern wood preservation. The great attention that is being given to this subject is certain to produce a more correct understanding in the future. The whole proposition of wood preservation, with its numerous ramifications, requires a peculiar combination of special study. We should have, not only a thorough knowledge of the characteristics and performance of the wood, but also the chemistry of the preservative and the mechanical knowledge of plant operation. Lastly, the commercial instinct, or experience for purchasing the supplies, is necessary, in order to put the whole proposition on an economical and practical basis. Probably there is no better indication of the necessity of differentiating the subject into component parts and studying carefully each division than the large variation in the results of treatments that have been carried out, supposedly by the same standard process.

About a year ago, the writer's attention was called to the failure of a structure in which the timber had been impregnated with 20 lb. of oil per cu. ft. The trouble appeared to be that the original oil was of inferior quality, so that a large proportion of it disappeared after three years. The practice is rapidly passing of blindly plugging a stick full to saturation, irrespective of classification, the seasoning of the wood, and the exact quality of the preservative, leaving the principle of waterproofing finally to accomplish all. However, some modern specifications are still very unique in their generalities, for instance, the following is quoted from a specification for the treatment of wood paving blocks for a city of considerable size:

"The blocks will be treated by the injection of an impermeable and antiseptic mixture, 22 lb. per cubic foot, that contains at least 50% of inert oil of soft bituminous coal-tar or dead oil of coal-tar. The rest of the mixture will be composed of material adequate to offer impermeability to water."

What the contractor could be compelled to use for "the rest of the mixture" it would not be an easy matter to ascertain.

In relation to methods, it may be of interest to state that Mr. E. H. Hartman has applied for a patent for a combination process in which the seasoned wood is first placed in a hot bath of creosote oil and then treated in a cold solution of zinc chloride. The principle may be used with either the pressure or open-tank methods. It is unlike the Card process, as it is a two-movement method, and is different from the Allerdyce, inasmuch as the oil treatment is given first, instead of the solution of zinc chloride. Mr. Schreiber.

Probably the author has not given the light treatments with high-class oils the prominence that they deserve. Considerable development has been made in the empty-cell process, for both the pressure and the open-tank methods. Some prominent railroads are treating ties by the empty-cell pressure method, in spite of the fact that advocates of other processes have assailed the principles involved. The empty-cell pressure process seems to be of considerable importance, not only on account of the deep penetration obtained at a moderate cost, but because the wood comes out of the treating cylinders comparatively dry. Oil dripping is objectionable, not only on account of waste, but also because it often gives trouble after the lumber has been installed. In the 1910 Report of the Committee on Preservation of Poles and Cross-Arms, of the National Electric Light Association, an empty-cell process for the open tank is described. Briefly, the timber is treated by the ordinary hot and cold process in creosote oil, and then a third step is taken by reheating the timber in oil; this results in driving a portion of free oil from the wood. Here again is obtained the benefit of deep penetration with a limited quantity of oil. The importance of a proper quality of creosote oil in any empty-cell process is readily apparent.

One of the most pertinent subjects at present, in connection with wood preservation, is that of water-gas tar creosote *versus* coal-tar creosote. In 1908, approximately 17 000 000 gal. of coal-tar creosote oil were produced in the United States, while 39 000 000 gal. of the coal-tar creosote used was a foreign product. The scarcity of the domestic oil will undoubtedly continue, at least as long as the present conditions of by-product industry obtain. The quantity of water gas made in the United States is about twice as great as that of coal gas, and the creosote made therefrom is similar in many respects to that from coal-tar.

The writer was recently surprised to obtain from a contractor a bid for treating cross-ties in which the prices quoted were higher for water-gas creosote than for coal-tar creosote. It was understood, of course, that each oil was to have the same physical properties. This does not seem to indicate the alleged advantage, at least at present, and from the commercial standpoint, of using the water-gas creosote as an adulterant or substitute.

Some interesting papers have been presented recently, before the American Branch for Chemical Industry, by S. R. Church and J. M.

Mr. Schreiber. Weiss, and with the discussion have considerable bearing on the question of the value of water-gas creosote as a preserving agent. Mr. Weiss, whose paper had the caption of some experiments on the action of oils and tars in preventing mould growth, said in conclusion that the coal-tar creosote, as well as the undistilled tar, is antiseptically more efficient in about the proportion of 6 to 1. It is unfortunate that the chemistry of creosote oils is not well enough known to enable one to form more definite and authentic opinions on the value of the creosote oils, other than their physical characteristics, and it is hoped that further data will be obtained along this line. Although the antiseptic ratio between the oils of coal-tar and water-gas tar may not be as important where the timber is treated by the full-cell method, it certainly requires serious consideration where the treatment calls for a limited quantity of oil.

Mr. Tillson. GEORGE W. TILLSON, M. AM. SOC. C. E.—During the past eight or ten years, the speaker has given a great deal of attention to wood preservation as relating to wood pavement, and a great many of the matters referred to in this paper are subjects in which he has been interested and about which he has had considerable to do.

Wood pavements have been in use in America more or less since some time between 1840 and 1850, in Philadelphia and in lower Broadway, New York City. The woods used were pine, hemlock, and sometimes fir, as convenience suggested, and it is not strange that they were unsatisfactory.

Twenty years later there appeared the well-known form of wood construction called the Nicolson pavement, where the wood was more particularly selected and laid in a better manner, and was almost always white pine. No attempt was made to treat it in any way, however. The blocks wore unevenly, and soon became rough, so that they were not much better than cobbles, and soon went out of use.

About twenty years later—it seems to be strange that this wood renaissance, if it may be called such, appears in cycles of twenty years—the cedar block movement swept over the West, and carried almost everything before it in the larger cities, such as Detroit, Chicago, Kansas City, Minneapolis, and St. Paul. These pavements were of very short life, and were seldom renewed, except in Chicago, where the street mileage was so great that it was necessary to use a cheap, even if a temporary, material.

About ten years ago the officials of Indianapolis started to lay a treated wood block pavement. The industry was new then, and comparatively little attention was paid to the kind of wood, its particular character, the quantity of oil per cubic foot, or the character of the oils. The result was that the pavement bulged, but it was so satisfactory in certain particulars that it was deemed best to experiment

further, and the result was the development of the wood pavement industry as it exists to-day. Mr. Tillson.

Creosote oils are volatile, and it was considered questionable whether or not the lighter oils which were used would remain in the pavement, and, not only preserve it from decay, but also prevent the deformation of the pavement after it became comparatively old, as the object of the treatment is, not only to preserve the wood from decay, but to prevent it from absorbing water and becoming deformed when wet, or loose when dry. The study of that question probably brought out the mixing of resin with the creosote oil, and the treating of wood blocks with that mixture, which was called the creo-resinate process. It was described in detail* before this Society in 1900 by F. A. Kummer, M. Am. Soc. C. E.

Probably the first pavement of this kind ever laid, certainly in the East, was that put down on the west side of Tremont Street, Boston, in 1900. The speaker has kept pretty close watch of that pavement during the last ten years; and saw it the last time during this winter, when it was in good condition. The use of the resin, or the natural development of the resin industry, caused an increase in its price, making that treatment expensive, and it was thought, by a good many engineers who were interested in the subject, that possibly a heavier grade of oil, of greater specific gravity, might serve the same purpose as the resin.

In studying this question, the experiments noted in Tables 2 and 3 were made in the Bureau of Highways, Borough of Manhattan:

Four samples of oil were selected for these tests, two having a light specific gravity and two being heavy oils. The constitution of the oils, when subjected to distillation, is shown in Table 2.

TABLE 2.—Constitution of Creosote Oils Used in Experiments Made by the Bureau of Highways, Borough of Manhattan.

No.	Specific gravity.	Distillate.			
		To 315° C.	315° to 370° C.	Total to 370° C.	Residue.
S— 997	1.055	82.5%	8.5%	91.0%	9.0%
S—1 003	1.180	33.4%	13.4%	46.8%	53.2%
S—1 008	1.065	83.1%	8.5%	91.6%	8.4%
S—1 017	1.190	35.4%	10.9%	46.3%	53.7%

The loss in weight of these oils, when maintained at 120° Fahr. for the number of days indicated, is shown in Table 3.

* *Transactions*, Am. Soc. C. E., Vol. XLIV, p. 181.

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TABLE 3.—LOSS IN WEIGHT OF CREOSOTE OILS AT 120° FAHR.

No. of days.	S—997 Sp. grav., 1.055. Total loss.	S-1 003 Sp. grav., 1.180. Total loss.	S—1 008 Sp. grav., 1.065. Total loss.	S—1 017 Sp. grav., 1.190. Total loss.
1............	13.3%	6.2%	10.9%	3.8%
2............	20.8%	9.1%	18.2%	5.7%
3............	26.8%	10.7%	24.2%	7.4%
6............	41.1%	13.3%	39.1%	9.9%
10............	53.1%	16.0%	49.7%	12.7%
15............	58.9%	18.1%	54.4%	15.0%
22............	63.4%	19.1%	59.1%	15.8%
29............	67.0%	19.6%	61.9%	16.2%
36............	69.1%	20.3%	64.1%	16.7%
43............	70.9%	20.8%	66.1%	17.3%
50............	72.3%	21.2%	67.5%	17.6%

The question of using the heavier oil in New York City and eliminating the resin was discussed at great length by a committee made up of the Chief Engineers of the Bureaus of Highways in the different Boroughs, the Chief Engineer of the Board of Estimate and Apportionment, and the Chief Engineer of the Finance Department. This committee consulted with manufacturers in other localities, and finally recommended an oil with a specific gravity of 1.12 at 38° cent., and one in which the distillate between 255° and 315° cent. should have a specific gravity of not less than 1.02 at a temperature of 60° cent. The object of this was to allow the lighter creosote coal-tar oils to be mixed with the heavier products of water-gas tar, producing an oil which would have a specific gravity of 1.12, and in so doing not to use more than 50% of water-gas tar oil. This specification has been in use for nearly two years, and has proven satisfactory. The committee was not willing to allow a product made entirely from water-gas tar to be used, but thought it would be safe to allow the coal-tar oil to be mixed with an equal portion of water-gas tar oil; and the restriction of the 1.02 at a temperature of 60° cent. prevents a greater quantity of water-gas tar being used. In deciding this question of the oil, the committee felt that, not simply a preservative, but also a water-proofing oil, was required.

At a meeting of a committee on wood block specifications, held in Chicago in February, 1910, for the purpose of standardizing paving specifications, there was adopted a specification for oil which provided that it should be a coal-tar product, free from all adulteration, with a specific gravity of 1.10 at a temperature of 38° cent., not more than 3% of the oil to be insoluble by hot continuous extraction with benzol and chloroform.

At this meeting the committee had before it representatives of all the leading block pavement manufacturers in the country, and the oil specifications referred to were adopted unanimously.

In October, 1910, a committee on standard wood block specifications, appointed by the American Society of Municipal Improvements, reported practically the same specifications for oil. Mr. Tillson.

Mr. Lamb has said that the cost of the heavy coal-tar oil increased very materially the cost of the pavement. As a matter of fact, in the Borough of Manhattan, bids have been received in competition for both coal-tar and water-gas tar oil, and in only one case has the bid for the water-gas tar oil been lower than the others. During the past season bids have been received in the Borough of Manhattan from two firms, one furnishing blocks treated in Mobile, Ala., and the other blocks treated in Norfolk, Va. Both the oils used comply with the specifications. The speaker has been in communication with representatives of St. Louis and Minneapolis, and has been informed that they have no trouble whatever in getting oil of this quality. He also knows that oil of this character is manufactured at Indianapolis by a private contractor.

A great deal of comment and criticism has been made on the heavy oil required by the different specifications. The speaker has studied the matter very carefully and talked with a great many people who are well posted on the subject, and he is perfectly satisfied that the best practice of to-day is to use the heavy oil. He is also satisfied that there is no trouble whatever in obtaining such oil if the party desiring it is willing to take the proper means to obtain it.

Mr. Lamb has referred to blocks splitting in a pavement laid on a bridge in Brooklyn. The speaker has driven over that bridge a great many times and admits that that statement is correct; but he also knows that the blocks used were shallow, and were laid on an old board foundation which was loose and uneven, and allowed the blocks to wobble materially under traffic. The blocks, although split, sustained the traffic over the bridge at least three or four times as long, to the speaker's knowledge, as the plank surface which had been maintained there previously.

When wood pavement was first introduced in the Borough of Manhattan it was laid on three streets: On Warren Street, west of Broadway, where the traffic is heavy; on Twentieth Street, between Broadway and Fifth Avenue, where the traffic is medium; and on Ninety-eighth Street, between Central Park West and Amsterdam Avenue, where the traffic is very light. These pavements have been down now a little more than 6 years, and show no appreciable wear. If the oil used in the wood will preserve it from decay and also prevent deformation, the pavement on Ninety-eighth Street should last 25 or 30 years, and that on Twentieth Street nearly as long. When both the water-proofing and preservative action are taken into consideration, to the speaker's mind, there seems no doubt that the heavy oil should be used.

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ERNEST F. HARTMANN, ASSOC. AM. SOC. C. E.—Wood preservation is undeniably of growing importance, and it is regrettable that there is not available a single textbook which will enable the engineer to form definite conclusions as to the value of this or that method, or of this or that preservative, according to the conditions with which he is confronted. This, no doubt, is due somewhat to the difficulty of stating even general principles which will take into consideration the structure of the timber, the soil, the climatic conditions, and the conditions to which the timber will be exposed. As an instance of the difficulty of laying down general rules: a treating plant at Springfield, Ill., finds it impossible to treat red oak satisfactorily, while another plant owned by the same company, and located at Marion, Ill., only 150 miles distant, is treating the same kind of timber successfully. Though the timber is of the same species, the difference is due to the fact that that at Springfield is grown at an elevation of 1 400 ft., while that at Marion is practically swamp-growth.

As the author reviews the report of the Special Committee of 1885, it may be well to note that material progress has been made since that time.

It is now conceded that the decay of timber is caused by fungi, but in 1885 this was still a much mooted question. There is now more information regarding the way in which fungi attack timber, that is to say, the manner in which timber becomes infected, so that to-day the proper form of treatment can be more readily prescribed.

The American's inborn ingenuity has resulted in putting the United States far in advance of Europe in the mechanical equipment of treating plants; and, because of the larger demands for treated timber from individual users, the average American plant is double the size of most of those found in Europe, while another cause, which is to some extent responsible for the larger size and better mechanical equipment of the average American plant, is the difference in the cost of labor.

In the matter of preservatives, engineers still look to Europe for guidance, though the bulk of the zinc chloride used in America is now manufactured here. Until the coal-tar industry in the United States materially develops, Europe will supply the greater part of the coal-tar distillates. The development of the gas industry in the United States resulted in a new by-product and a consequent desire to find a market for it. It is very much to be regretted that, owing to the shortage of true coal-tar distillates, considerable material of very questionable value is being used for the treatment of timber. While present standards demand pure and unadulterated creosote oils, the methods of analysis generally used do not facilitate the detection of adulterations in such materials. Failures of treated timbers have frequently been traced to the use of low-grade or adulterated oil. In the light of this

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knowledge, and for the protection of the purchaser, he should be informed as to whether coal-tar creosote, or mixtures with water-gas tar creosotes, are used. In the interests of true wood preservation, the speaker favors the calling of things by their right names.

In numerous cases inspectors have rejected treated timber only to find themselves over-ruled by their superiors, the defective timber accepted, and the same treating company favored with further orders. If those instrumental in establishing standards of inspection continue to over-rule inspectors who are endeavoring to carry out their instructions, one cannot hope for a higher standard, either in results to be obtained or in a more honest endeavor on the part of the manufacturer to furnish the best product.

The author has found worthy of recognition two basic processes differing only in the character of the preservative used. As a basis of classification, he might have used not the preservative itself, but the method of its application, that is, the brush, open-tank, and the closed-cylinder or pressure processes. These came into use in the order named, are in use to-day, and have all been developed.

The brush method dates back to ancient history, and at the present time it is becoming the rule to apply the preservative in a heated state.

For practical purposes the open-tank process dates from 1832, when Kyan adopted it, his patent covering the preservative. In the open-tank method of to-day sometimes two baths instead of one, and occasionally even three, are used. During the past six years it has been developed very considerably, and its value has been well demonstrated in experimental work in which the speaker is interested. Any process which will make it possible to treat seasoned pine so that an absorption of preservative of 20 lb. per cu. ft. can be obtained in 5 hours, is deserving of serious consideration. The speaker's experimental work during two years was confined to pine, as that bids fair to remain one of the most available timbers adapted to preservative treatment in a considerable portion of the United States.

The third or pressure process was patented by Bethel in 1838; as he used coal-tar oils, his method has come to be known as "creosoting." The development of this process has been very marked in the United States.

Mr. Buehler agrees with the fifth cause of failure as reported by the Special Committee in 1885, and adds that "undue haste and consequent poor work" has "probably had more to do with failures, then and now, than any other cause." If this be true—and undeniably it is—engineers should ponder longer over this conclusion, and endeavor to profit by the failures as far as they have been made known.

Engineers can, with profit to themselves, emulate the example of the late Octave Chanute, Past-President, Am. Soc. C. E., Chairman of

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the 1885 Special Committee, who from 1885 to the time of his death continued actively in the wood preserving field. His contributions and discussions before this and other Societies entitle him to consideration as the mentor of the wood preserving industry in the United States. Though he experimented with many processes, he continued the use of the Wellhouse process, and, becoming convinced that additions of glue to the zinc chloride solution made the latter less fluid, and that it therefore did not penetrate as deeply into the wood, he improved that process in 1901 by adding a third movement, separately injecting first the zinc chloride, then the tannin, and lastly the glue, thus it will be seen that he avoided the "haste" given as the greatest cause of failure.

Table I, presented by the speaker before the New York Railroad Club,* gives the results obtained in the Texas experimental track, and shows that ties treated by Mr. Chanute's Company by the Wellhouse process gave an efficiency of 60% for ties remaining in good condition, while, by contrast, those treated by a different company, though using the Wellhouse process, gave an efficiency of only 34.1 per cent.

This difference must be attributed to the way in which the work was done; the short-lived ties may have been treated when the wood was inadequately seasoned, or the process may have been carried out carelessly, or an insufficient quantity of chloride of zinc may have been injected. This demonstrates forcibly that the best results will not be obtained with any process unless the work is performed skilfully and honestly.

In speaking of the quantity of preservative to be used if the timber is to be protected against decay, the author states that the locality in which the timber is to be used must be known. With present knowledge of the stability of certain constituents of coal-tar distillates, it should also be known whether the timber is to be fully exposed to the air, as in trestles, or whether it is to be buried in soil, or covered with ballast. It has been established that all the lower constituents of the oil, that is, the naphthalene fraction and below, will disappear entirely within 4 years from timber fully exposed to the air. The relative value of the quantity and quality of preservatives used are here as elsewhere deserving of consideration.

The author differentiates the oils into those suitable for the preservation of timber, for paving blocks, and, possibly, for protection against marine insects. The speaker would group such oils with reference to their value for protecting: First, timber in the ground or covered with ballast, such as ties; second, timber exposed fully in the air, such as structural timber, and third, timber exposed to the attack of boring animals in water, such as piles.

Mr. Buehler states that practically no bridge or structural timber is air-seasoned, and, further, that conditions are such that probably it

* *Proceedings*, New York Railroad Club, February, 1910, p. 1963.

will never be possible to air-season it. It is also well known that it is impossible to season such timber artificially, by steaming or vulcanizing. Where safety stresses have to be calculated carefully, it is extremely dangerous to treat green timber by the methods still generally practiced. The author recommends seasoning in oil, and with this the speaker heartily agrees, though it is to be regretted that Mr. Buehler has made no mention of the open-tank method, which developed this particular advancement. Even railroad companies owning treating plants cannot spare the time necessary for such oil seasoning; such plants are erected usually to supply the demand for ties; while bridge or other structural timber receives but scant consideration. Mr. Hartmann.

It is almost impossible to prevent timber from season checking when it is exposed in locations where it can give off moisture. Even if the timber has received a creosote treatment of 10 lb. per cu. ft., such season checking will occur. A 10-lb. treatment does not mean that that quantity of preservative is distributed evenly throughout each cubic foot of the stick. It means a penetration of only about 1 in., and, if season checks open to a greater depth than the treated zone, infection by fungi becomes possible.

The author states that the causes of decay of wood are now generally understood, but this is true only in so far as it relates to the general fact that the principal agency of decay is a fungous growth.

In December, 1898, the International Association for Testing Materials appointed a committee charged with the solution of the following problems: First, how can one tell whether wood contains any germs of infection (spores or mycelium); in other words, has one the right to reject wood as defective or must it be accepted? Second, what can be done to escape the attacks of fungus or to prevent its development if the wood contains such germs?

In the report published in 1902, the Committee stated in conclusion: "It seems that if the solution of the first question set by the International Association is not much advanced, the same is not true of the second, which is really much more important."

It is easy to see that wood is attacked by fungi when fruiting bodies are on the timber, or when the timber has begun to lose strength or hardness; but, in the absence of such obvious indications, it is impossible to state that it does not contain in its season checks or on its surface some fungus spores which may develop under favorable circumstances.

The speaker, in his experience during the past 10 years, has found that there is a very widespread belief that the decay of structural timber starts in the interior of the stick; but few of the fungi which bring about the decay of structural timber grow in living trees. Where such timber decays, the fungus which is responsible must get into the wood from the outside. The manner of infection, therefore, is of con-

Mr. Hartmann. siderable importance, and warrants a closer inquiry with reference to the treatment of structural timber.

Dr. Robert Hartig, whose "Zersetzungserscheinungen des Holzes," though published first in 1878, remains to-day the finest example of the study of the decomposition phenomena of wood, in several of his later books refers to the infection of timber in seasoning checks and the manner in which this infection is the cause of the internal decay usually termed dry rot.

Five years ago in a discussion before this Society of a paper* on "The Inspection of Treatment for the Protection of Timber by the Injection of Creosote Oil," Mr. James C. Haugh called attention to the failure of piles on the oft-referred-to Lake Pontchartrain Trestle, the decay occurring at the heads of the piles, and he states further, after an observation representing the experience gained in 22 years of maintenance as Resident Engineer:

"There were more failures in caps than in timbers of any other size. This * * * was due to the size of the timbers not admitting of thorough seasoning, consequently, they 'checked' afterward. This checking extended beyond the point to which the creosote oil penetrated."

Modern specifications for the use of creosoted bridge or trestle timber usually contain a clause to the effect that:

"All cut ends, mortises, tenons, and other incisions of the original surface of creosoted timber shall be protected by not less than four coats of creosote oil, applied boiling hot with a brush or mop. In the case of mooring piles, fender piles, and other timber having the cut end exposed to the weather, the portions thus exposed shall have, in addition to the creosote oil, a heavy final coat of paste made of equal parts of unslacked lime and creosote oil, applied hot."

Where does the decay of structural timber usually commence? Is it not at the ends, joints, or mortises; and, if for creosoted timber the brush method is necessary to protect the ends, may not this method be equally efficient for protecting the parts of the timber less susceptible to decay?

Could not these season checks, which are unavoidable, be run full of oil by the brush method, and such treatment renewed periodically if necessary? The reasons for such renewals must be evident if one takes into consideration the impossibility of obtaining seasoned timber at the time of construction. Seasoning checks which open up during the fall should be protected against infection at a time of the year when these checks can be properly reached with the preservative. Again, under certain climatic conditions, seasoning checks will open to a greater depth, and it would also be necessary to protect the timber where thus exposed, hence the necessity of renewed brush applications.

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* *Transactions*, Am. Soc. C. E., Vol. LVI, p. 10.

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It may be well to refer to another method of application, namely, the use of spraying or painting machines. The preservative can be heated in an iron drum to which a painting machine is attached, and the use of this method will much better permit of the treatment of lateral or horizontal surfaces, that is to say, it will better enable the preservative to penetrate thoroughly into all seasoning checks.

Is it not possible to prevent infection by fungus germs, or to destroy those which may be in season checks or on the surface by an immersion of the timber in a bath of a satisfactory antiseptic? Taking into consideration the force of capillary attraction inherent in wood, will not such a treatment after the framing of the timber insure a better protection at all cut surfaces?

If Dr. Hartig and Dr. C. Freiherr von Tubeuf—who are recognized as the highest authorities on diseases of timber—have correctly established the principal causes of the decay of structural timber, which principles are re-stated in Bulletin 149 of the United States Bureau of Plant Industry—will the immersion of seasoned timber in a suitable antiseptic protect it against infection and destroy the germs of fungi in or on the timber?

The manner of infection being now known and understood, the danger of seasoning dimension timber by ordinary methods being acknowledged, and likewise the practical impossibility of framing timbers before creosoting at plants located a considerable distance from the point of construction, it is imperative that other methods of treatment be used.

Though the author states that he has made no attempt to discuss the various preservative methods developed since 1885, it would be of interest to obtain his views on the possibility of the open-tank method answering satisfactorily for treating structural timber, because of its availability at the point of construction, where it may be used for the treatment of the timber after framing. It would also be of interest to have the author's opinion on the value of the brush method for protecting seasoning checks by the subsequent application of a preservative.

Is water-proofing necessary in order to get a satisfactory wood block pavement? From the discussion it is evident that the author's view on this point is concurred in by some, but all the experience available does not seem to corroborate it. The speaker has no desire to discuss the specifications for wood block pavements in use to-day, but those conversant with the subject are aware of the many changes made during the last decade. Some engineers have insisted on having wood blocks laid on a bridge "sent home" as tightly as possible. The resultant "buckling" after heavy rains showed this to have been wrong, and after relaying, with due allowance for expansion, no more trouble occurred. The omission of proper expansion joints has caused the

Mr. Hartmann. same trouble in the streets of many cities. As apparently showing that it is not necessary to water-proof wood blocks, experience in Paris, Berlin, London, Toronto, Cleveland, New Orleans, Portland, Ore., Seattle, Tacoma, and other cities might be cited, even though the traffic on some of the streets was light while on others it was extremely heavy. In the cities above named the blocks were treated superficially and laid on a sand cushion, the joints were filled with sand, and the pavement gave entire satisfaction. In the report of the Special Committee of 1885 will be found extracts from a report by Dr. W. C. Tilton, of Washington, D. C., made to the Government Commissioners in 1872. He stated that paving blocks treated by the Seely process, with about 4 lb. per cu. ft., presented a satisfactory appearance of saturation, and in Pittsburg and Cleveland, had lasted about 10 years, or some 4 or 5 years longer than if they had been in their natural state. One of the oldest tests made with treated wood blocks is reported by the New Orleans Gas Light Company. In 1878, blocks treated by the open-tank process were laid by this company in its yard, and at this date it is reported that they are in good condition.

A paper by Mr. Charles Mason,* in 1894, brought out the importance of expansion joints. London was at that time laying large quantities of yellow deal blocks (closely resembling pine), and was treating them superficially.

Europeans lay stress on the necessary antiseptic character of the treatment, for sanitary reasons. The adulteration of the proper oils with non-germicidal water-gas tar creosotes or filtered or unfiltered tar does not tend to produce a more hygienic pavement. The scavenging of pavements is also worthy of consideration. The oils are very likely to ooze out of heavily charged blocks during hot weather. This "bleeding" may be due to other causes. If the oils used have been mixed with filtered or unfiltered tar, or if the pavement has received an excess top dressing of paving pitch, the oil and tar will adhere to the wheels of vehicles and the shoes or clothing of pedestrians, and cause not only inconvenience but damage. The experience on Market Street, Philadelphia, and also in Chicago during 1910 has shown that "bleeding" is a serious matter.

In all European cities the height of the blocks has been steadily increased from 8 to 13 and even 15 cm. Experience with blocks varying from 2 to 5 in. high leads the speaker to believe that their holding power is at least somewhat dependent on their height.

Proper drainage of the foundation is another factor; therefore a bed of sand is preferable to concrete. The success with 5-in. yellow pine blocks, treated by the open-tank method, in Cleveland, Ohio, and laid on the Abbey Street Viaduct at an angle of 45° with the center line of the roadway, offers another method of overcoming expansion

* Before the Incorporated Association of Municipal and County Engineers, in London.

without relying on expansion joints. Other tests with which the speaker is familiar, including wood block pavements in wash-houses of breweries, where extreme conditions are met, are a further indication that the "exploding" or "buckling" is frequently due to insufficient or improper expansion joints. If it is possible to get a satisfactory pavement with blocks treated by immersion in heated preservatives, it should also be possible when the blocks are treated with, say, from 10 to 16 lb. per cu. ft. of unadulterated preservative oils. Mr. Hartmann.

A. L. DEAN, ESQ.*—Mr. Buehler has traced in a brief way the history of timber preservation since 1885, when the Report of the Special Committee was presented, showing that the development subsequent to that Report was largely an outgrowth of fundamental processes then in use. Mr. Dean.

The 1885 Committee found that the failures of the previous years had been fully as instructive as the successes, and, in a limited way, that is true of the progress of timber preservation between 1885 and 1910. We have learned certain things which cannot be done, fully as thoroughly as things which can be done.

For example, it has been shown conclusively that excessive steaming, particularly at high temperatures, is injurious to timber, and not permissible under ordinary circumstances. Furthermore, it has been shown quite clearly that whatever virtue there may be in steaming timber, as a preliminary step in processes of impregnation, this virtue is not due to the removal of any substantial percentage of the water from the timber. Steaming alone practically fails to remove any water, and, even with a subsequent vacuum, the percentage removed is usually small.

Another very instructive thing was the Hasselman process, which serves to show from what unexpected sources failure may proceed. In this process the wood was boiled in a solution consisting of a mixture of sulphates of a number of different metals, including copper, aluminum, and iron, with the result that a timber showing marked resistance to the attack of fungi was produced, which was clean, and treatment of which required but inexpensive equipment. Timber treated by this process, however, became extremely brittle, and the difficulty was found to lie in the fact that the sulphates of weak bases such as iron, aluminum, etc., became hydrolyzed, especially at high temperatures, with the formation of some free sulphuric acid; so that the process involved the steeping of wood in a dilute solution of sulphuric acid.

This defect caused the abandonment of the Hasselman process, although a modification of it—the Wolman process—has made some progress abroad. In this modification the formation of sulphuric acid

* Asst. Professor of Industrial Chemistry, Yale University.

Mr. Dean. was overcome by the introduction into the solution of a salt of weak acid and powerful base which, when hydrolyzed, would set free alkali sufficient to neutralize the sulphuric acid from the metallic salts present.

It may not be out of place to consider in a brief way along what lines changes and progress in timber preservation are likely to take place. There are to-day certain tendencies which indicate the direction of progress more or less clearly, and lead to the conclusion that it will proceed along two general lines: (1) The development of the art of timber preservation itself; (2) The development of specifications and methods of control.

Turning attention first to the development of the art of timber preservation, it is to be noted that there is always a balance between the cost of a process and the efficiency, and any step which tends to reduce the cost without impairing the efficiency, or *vice versa,* raises the efficiency without raising the cost proportionately, is in the right direction. It is to be expected that more complete information will be obtained regarding the best methods of distributing preservatives in wood, and the value which is to be placed on uniform and deep penetration.

According to present practice, but little attention is paid to the distribution of either creosote oil or zinc chloride solutions. The specifications call for the absorption of a certain number of pounds of preservative per cubic foot of timber, and at the treating plant it is considered that they are fulfilled if the gauges indicate that the required quantity of preservative has been injected into the timber, without any reference to the uniformity of its distribution.

Some attention seems to have been given to the question: Is it better to allow a certain quantity of the preservative to penetrate a short distance, thoroughly saturating the wood as far as it goes, or to get a deep penetration with a thin uniform distribution of the same quantity of preservative? The development of the latter conception is to be found in the various empty-cell processes. Without resorting to these methods of treatment, regarding which there is a good deal of argument, it is still possible to improve the distribution by a proper classification of timbers and regulation of pressures and temperatures. Where several different species, or timbers with different degrees of seasoning, or widely varying proportions of heart and sapwood, are included in the same cylinder charge, it is not to be expected that a uniform distribution of the preservative will be effected, because the more porous and drier portions will take up vastly more than their share, and the more resistant parts will receive but little.

As far as new preservatives are concerned, it would appear that there is not likely to be much change in the use of the different metallic salts now utilized. If some unexpected difference in price

should be established, there might be an inducement to change these metallic salts, but such price changes are not probable. Mr. Dean.

In the case of the oils, the question of value for timber preservation of the distillates of water-gas tar is of considerable importance. Something has already been said in this discussion regarding the value of water-gas tar oil; and, in view of the somewhat confused and inaccurate conceptions which seem to be current, it may be worth while to point out some characteristics of water-gas tar and its possibilities. This tar is formed by the decomposition, at very high temperatures, of the petroleum used for carbureting water gas. In this carbureting process something like 25% of the oil used appears in the form of tar, the other 75% having been formed into gaseous products which serve to give illuminating qualities to the gas. This tar differs from coal-tar in some particulars, and resembles it in others. It contains no, or almost no, free carbon or soot, which is present in coal-tar, often to the extent of 25%, and it contains no tar acids or phenols. On distillation, water-gas tar yields distillates which resemble those from coal-tar, but contain no tar acids, and show some differences in the nature and proportions of the hydrocarbons. The heavy oil resembles coal-tar creosote in containing large quantities of naphthalene, and has been used to some extent as a timber preservative. The water-gas tar itself, with no treatment further than the removal of the low-boiling oils, is suggested as material for treating paving blocks, as it does not contain the large percentage of free carbon which renders the use of coal-tar difficult. The value of this water-gas tar and its distillates as timber preservatives is not definitely known, and it is of prime importance that it be ascertained, so that, if they are of service they may be used, and if they are of little or no value they may be guarded against.

As indicated by Mr. Buehler, there is considerable interest at present in combination treatments, in which both metallic salts and oils are used, and developments along this line are to be expected.

Considerable interest has attached to the use of oils which do not possess any antiseptic powder, but are of heavy asphaltic character, and are injected in sufficient quantities to make the stick of wood practically moisture-proof. Treatments of railroad ties along these lines have been made by the Santa Fé Railroad, and, as far as known at present, indicate that a process of this sort may possess distinct value.

In the last few years there has been considerable activity in the development of simplified methods of treatment, such as the open-tank or non-pressure processes, in which inexpensive and small apparatus is substituted for the expensive equipment of an ordinary pressure plant. These processes, if successful, may be suitable for the user of relatively small quantities of lumber, who desires some

Mr. Dean. preservative treatment but does not care to construct an expensive plant.

The necessity for better specifications and better control of timber preservation has made itself felt within the last few years. There is great difficulty in drawing specifications, because of the complexity of the whole subject of timber preservation. It is essentially a biological problem, and, like most problems of that kind, is complicated by the great variation in vital processes. This makes itself apparent in the differences in the nature of the wood, often when of the same species; and, furthermore, the decay of timber is due to life processes of living plants, and the conditions which may affect the vigor of the attack of the fungus on the wood are numerous and not wholly understood.

The complete specifications for timber preservation must control the wood which is used, its species, grade, and degree of seasoning; they must control the character of the preservative, and the processes of impregnation, which latter item includes the artificial seasoning, if such be used, and the method by which the preservative is injected.

The quantity of preservative must be specified, and it would appear that a further development, in the direction of specifying the degree of distribution of this preservative, is likely to come. In this matter of distribution, it would appear that there may be a divergence of interest between the engineer who specifies treated timber and the contractor who does the work. One paragraph in the paper suggests such a possible divergence. Speaking of the strength of zinc chloride solutions used, the author says:

"The strengths of the solutions vary from 2 to 5%, depending on the character of the timber to be treated; naturally, the denser the timber, the denser the solution."

This would indicate that, if a specification called for ½ lb. of dry zinc chloride per cubic foot of timber, it would be to the interest of the treating plant to use a strong solution in case the timber offered a marked resistance to impregnation, since, by the use of a more concentrated solution, a much smaller volume would be needed to carry the same weight of zinc chloride and less pumping would be required. With this smaller volume there would naturally be a much shallower penetration, so that the result would be a stick with a thin layer of wood in the outer portion containing an excessively large quantity of zinc chloride, while the interior would be wholly unprotected. Naturally, the deeper the penetration and the more uniform the distribution, the weaker must be the solution used, consequently, the larger the volume of solution to be injected.

At any rate, by specifying the temperatures and pressure to be used and by seeing that the timber is graded properly before treatment, it is possible to obtain an approximately uniform distribution. In the present status of the art the distribution is ordinarily very unequal, so

that the examination of different sticks in the same charge, or even different portions of the same stick, indicate decided differences in distribution. Mr. Dean.

Clifford Richardson, M. Am. Soc. C. E. (by letter).—It is evident that the preservation of timber by treatment of various descriptions, which is now attracting so much attention, is by no means on a satisfactory basis. It is still solely an empirical industry, and not conducted in a rational way. Unfortunately, the situation is much clouded by the attempts of various interests to control particular parts of it. Further, no attempt has been made to preserve an adequate record of what has been done in the past and of the results attained. Organized effort must be made in this direction before any data will be obtained from which conclusions of definite value can be drawn. In the meantime, in addition to arranging for an adequate series of service tests, an investigation of the conditions under which wood decays or deteriorates should be undertaken, in properly equipped laboratories, by chemists and biologists. This may properly fall within the province of the Forest Products Laboratory, which, it appears, from a paper presented at the last Annual Convention of the Wood Preservers' Association, is already taking up the subject with special reference to the determination of how much moisture is necessary for the growth of fungi and other organisms which produce decay, a matter of the greatest interest. It is well known that dry wood will not rot, and that the same is true of wood which is continually beneath the surface of water. What is the most favorable degree of moisture for decay, and what are the limits within which it will occur in various climates, at different temperatures, and for wood of different species and conditions of growth? Such data are not now available. Mr. Richardson.

It is generally recognized, however, that moisture is necessary to produce decay. Is it not reasonable to infer that if timber can be water-proofed to such an extent that moisture cannot exist in the fibers of the wood, decay will not set in? If the the water-proofing material is not such as to accomplish this, that is to say, if it will in itself take up a certain quantity of water, it will be necessary to have an antiseptic present to prevent organic growth which will cause decay. On this ground, two systems of timber treatment may exist, and both be found satisfactory; one in which the impregnating material acts solely in water-proofing the wood and preventing the growth of organisms because of the absence of the necessary quantity of water for this purpose, and the other in which the wood is not sufficiently water-proofed to accomplish the preceding result, but the growth of organisms is prevented by the presence of some substance, such as those of the phenol series or inorganic salts. If water-proofing is complete, no antiseptic is necessary; if it is incomplete, one must be present. The truth of these assumptions, of course, can only be demonstrated by service tests,

Mr. Richardson. and sufficient data are not available, at the present time, for any definite conclusion. Reasoning by analogy and from the data which are available, it seems probable that the assumptions will, eventually, be found to be true. A danger lies, however, in the fact that a method or material may be condemned by the result of service tests where new and untried material may not have been used properly, and not injected into the timber in a way to develop its capacity for preventing the growth of organisms.

On the basis of what has been previously stated, materials for impregnating and preserving timber may be classified as follows:

(1) Materials which do not in themselves render timber perfectly water-proof, but carry an antiseptic substance which prevents organic growths;

(2) Materials which render timber water-proof to such an extent as to prevent organic growth, although they may not contain antiseptic substances in such amount as to do so.

Under these headings the various materials used for treating timber may be classified as follows:

(1) Inorganic salts, such as zinc sulphate, mercuric chloride, and copper sulphate;

Creosote oils, and heavy oils and tars carrying phenols;

(2) Asphaltic and semi-asphaltic petroleums;

Tars and bituminous substances containing but a small amount of antiseptic material or none.

Of course, materials of the two classes can be mixed in different proportions, with the object, in certain cases—such as the protection of piles from the attack of the *teredo*—of obtaining the benefit of the desirable properties of both substances.

The writer believes that there is a future for the use of the purely water-proofing materials, for the reason that they are more stable, less volatile, and less soluble in water than the creosote oils and inorganic salts, and consequently remain for a longer time in the fiber of the wood.

MEMOIRS OF DECEASED MEMBERS.

WILLIAM FOSTER BIDDLE, M. Am. Soc. C. E.*

DIED AUGUST 10TH, 1910.

William Foster Biddle was born in Philadelphia, Pa., on August 18th, 1834. He was graduated at the University of Pennsylvania in 1852, and took up the practice of engineering. He held successively the positions of Leveler on the Virginia Central Railroad (now the Chesapeake and Ohio), under Charles Ellet, Jr., up to 1855; Resident Engineer in charge of Construction on the Mine Hill and Schuylkill Haven Railroad (now the Philadelphia and Reading), up to 1857; Assistant to the Chief Engineer of the Illinois Central Railroad at Chicago, up to 1860; and Superintendent of the Eastern Division of the Ohio and Mississippi Railroad, at Cincinnati, up to October, 1861.

In 1862 and 1863 he was in active military service in the Civil War, with the rank of Captain (on the staff of General McClellan, with whom he had been previously associated in engineering). His record of service with the Army of the Potomac, from its formation until after the battle of Antietam, was that of a brave and gallant officer.

He was Superintendent of the Freedom Iron Works, Pennsylvania, up to 1865, and was Vice-President of the Lehigh Coal and Navigation Company (Lehigh and Susquehanna Railroad), until 1869. In 1874 and 1875 he designed, located, and constructed mining water-works in Venezuela, South America. Later, he was President of the Millwood Coal and Coke Company, of Westmoreland County, Pa., with offices in Philadelphia.

Captain Biddle was ill for several months, following an attack of acute pleurisy in March, from which an empyema developed, necessitating an operation for the abscess which had formed in the pleural cavity, and from the effects of which he never recovered, septicæmia setting in. He died at South Bethlehem, Pa., at the home of his niece, Mrs. Henry S. Drinker.

Captain Biddle was a cultured gentleman, a man universally respected and greatly loved by those privileged to know him well. He was an able engineer, and, in addition to his membership in this Society, was an active member of the American Institute of Mining Engineers, and of the Union League Club of Philadelphia. His charming personality is best summed up in the following tribute to his memory which appeared in the *Philadelphia Ledger* of August 12th, 1910, which will be appreciated by all who knew him:

"A distinguished figure is lost to the finer life of Philadelphia in the death of Captain William Biddle. Though he had long passed his

* Memoir prepared by Dr. Henry S. Drinker, President, Lehigh University, and Mr. James McCrea, President, Pennsylvania Railroad Company.

threescore years and ten, no one ever had thought of him as an old man. His handsome face, his gentle speech, his whole gracious personality had the charm of perennial youth. A gallant soldier in the Civil War, an engineer of achievement, and always an active-minded citizen, his persistent personal vocation really was in music. Few musicians are as well-read as he in the literature of the pianoforte, and for many years there has been no one in Philadelphia more confidently to be counted upon for the support of all laudable musical undertakings. He was the musical editor of a hymnal that is a model of musical exactitude and taste not often found in such compilations. Until the past winter he was seldom missing from any important concert, and his absence will leave a gap not easily to be filled by one of his fine attainments, his gentle breeding, and his serene character."

Captain Biddle was elected a Member of the American Society of Civil Engineers on June 4th, 1884.

CLARENCE ALLAN CARPENTER, M. Am. Soc. C. E.*

DIED NOVEMBER 9TH, 1899.

Clarence Allan Carpenter, the only son of John Allan Carpenter, was born at Dedham, Mass., on August 26th, 1846. His father was a well-known contractor, having been connected with the construction of the Fitchburg Railroad, the Old Colony Railroad, the Lawrence Dam, and many other important engineering enterprises.

In 1863, when he was seventeen years old, Mr. Carpenter began his professional career as Chainman on the Adirondack Railroad. He was successively Rodman, Leveler, and Transitman, remaining with the company until 1865. From 1865 to 1867, he was in the service of the Whitehall and Plattsburgh Railroad, attaining the position of Assistant Engineer.

In March, 1868, Mr. Carpenter entered Union College at Schenectady, N. Y., intending to take the course in Civil Engineering, but he was obliged to leave in February, 1869, on account of trouble with his eyesight.

From May to November, 1869, he was Assistant Engineer of construction on the Neosho Branch of the Missouri, Kansas, and Texas Railway. From February, 1870, to May, 1871, he served as Assistant Engineer in charge of construction on the Little Rock and Fort Smith Railroad, and from May to October, 1871, he was engaged on the survey for the Southern Pacific, west from Van Buren.

In November, 1871, Mr. Carpenter returned East, and until June, 1872, was in the employ of the New York and Boston Railway as Assistant Engineer on construction. For the next four years (1872-1876) he was Assistant and Resident Engineer, respectively, for the Delaware and Hudson Canal Company, on the construction of the New York and Canada Railway.

From March, 1877, to March, 1878, Mr. Carpenter was engaged, as Contractor and Engineer, with the Sewer Department at Saratoga Springs, N. Y., and from March to November of the same year, he was employed as Assistant Engineer, in charge of the west end of the Plattsburgh and Dannemora Railroad, which was built by the State of New York.

In March, 1879, Mr. Carpenter again went West to the Central Branch of the Union Pacific Railway as Assistant Engineer in charge of construction, and in June, 1880, he entered the employ of the Chicago, Milwaukee, and St. Paul Railway, remaining with that road for eleven years in the following positions: 1880 to 1886, Assistant

* Memoir prepared by the Secretary from papers on file at the Society House and from a memoir published by the Association of Engineering Societies.

Engineer and Inspector of Bridges; 1886, Division Engineer; 1887, Division Engineer on construction of the Kansas City Line; 1888 to 1890, Principal Assistant Engineer, Bridge Department.

After severing his connection with the Chicago, Milwaukee, and St. Paul Railway Company, in 1890, Mr. Carpenter was engaged on surveys for the Atchison, Topeka, and Sante Fé System, in California, until he accepted the position of Division Engineer on the Northern Pacific Railroad, with headquarters at Helena, Mont.

In the fall of 1891, he was appointed Division Engineer of the Lake Shore Division of the Lake Shore and Michigan Southern Railway, which position he held at the time of his death. While attending to his duties, Mr. Carpenter was struck by a passenger train near Geneva, Ohio, on November 7th, 1899, and died from the effects of his injuries on November 9th.

On April 17th, 1872, Mr. Carpenter married Miss Annie M. Miller, of Johnstown, N. Y., who, with one son and three daughters, survives him. Mr. Carpenter's devotion to his family and home was one of his most marked characteristics.

Although quiet and unassuming in his manner, Mr. Carpenter was beloved for his personal qualities and respected for his ability as an engineer, by all who knew him. His reputation for care and accuracy was widespread. He had a rare capacity for detail, nothing connected with his work being of too little importance to claim his careful personal attention. He also had a broad and comprehensive grasp of the greater problems, which always won the confidence of his employers.

Mr. Carpenter was elected a Member of the American Society of Civil Engineers on May 2d, 1888. He was also a Member of the Civil Engineers' Club of Cleveland, Ohio.

GEORGE EARL CHURCH, M. Am. Soc. C. E.*

DIED JANUARY 5TH, 1910.

George Earl Church was born in New Bedford, Mass., on December 7th, 1835. He was of Puritan ancestry, and it is said that "he carried in his veins the bluest blood of New England." On his father's side he was directly descended from Richard Church, who, in 1632, went from Oxford, England, to Plymouth, Mass., where he married Elizabeth Warren, whose father, Richard Warren, came to America on the *Mayflower,* and was an ancester of General Warren, who fell at Bunker Hill. On his mother's side he was a lineal descendant of a daughter of Edward Winslow, who also came to Plymouth on the *Mayflower.*

While Mr. Church was quite young, his father died, and in his eighth year his mother moved to Providence, R. I. Here he attended the public schools, and at the age of fourteen held high rank in the Senior Class of the High School. When he was seventeen he decided to follow the profession of civil engineering.

In 1853 and 1854 he was engaged as Assistant Topographical Engineer on the State map of Massachusetts. In 1855 he was employed as Assistant Engineer on the Mississippi and Iowa Central Railway. In 1856 he was appointed Resident Engineer on the Hoosac Tunnel, but, when this great work was suspended for a time, he returned to Iowa as Chief Assistant Engineer on the location of a long line of railway in that State.

The financial crisis of 1857 having put a stop to the work, Mr. Church accepted an offer to carry out a railway project in the Argentine Republic as Chief Engineer, but on arriving in Buenos Aires, he found the country in such a disturbed condition that the work had to be postponed. The Government, however, almost immediately, appointed him a member of a scientific commission to explore the southwestern frontier and report on the best system of defence against the fierce inroads of Patagonian and Araucanian savages and allied tribes from the Andean slopes.

In 1860 Mr. Church surveyed and located the Great Northern Railway of Buenos Aires, and acted as Chief Assistant Engineer during its construction in 1860 and 1861. At the outbreak of the Civil War in the United States he gave up his position in Buenos Aires and embarked for New York on an American schooner. Reaching home, he was commissioned as a Captain in the Seventh Rhode Island Infantry, and was sent to the front.

During the war he served successively as Captain and Lieutenant Colonel of the Seventh Regiment, and as Colonel of the Eleventh and

* Memoir prepared by the Secretary from information on file at the House of the Society.

Second Regiments, Rhode Island Volunteers, and as a Brigade Commander, in the Army of the Potomac. He earned especial distinction at the Battle of Fredericksburg, where his regiment, the Seventh Regiment, Rhode Island Volunteers, suffered very great losses. He entered the fight as a captain and came out of it as lieutenant colonel in command of the remnant of his regiment. Afterward he was promoted to the colonelcy of the Second Rhode Island Infantry, and was sent to the Virginia Peninsula. He was present at the seige of Suffolk by Longstreet, and, later, commanded a brigade in a raid for the tearing up of the Norfolk and Petersburg and the Seaboard and Roanoke Railways, which was accomplished successfully after several hot skirmishes. He was then placed in command of the fortifications of Williamsburg until the term of his regiment expired.

At the close of the war Colonel Church was appointed Chief Engineer of the Providence, Warren, and Fall River Railway, which road, presented some difficult engineering problems.

In 1866 and 1867 he served in Mexico, and planned the campaign which resulted in the capture of Maximilian. During this campaign he also acted as war correspondent, and in 1868 was an Editor on the *New York Herald.*

In 1868 he went again to South America, and in a series of journeys explored a large part of the upper basin of the Amazon. He also explored the Bolivian affluents of that river, and was engaged for several years in opening up new channels for trade between Bolivia and Brazil. From 1872 to 1879 he was President of the National Bolivian Navigation Company and Chairman of the Madeira and Mamoré Railway Company.

In 1880 Colonel Church was appointed United States Commissioner to visit Ecuador and report on political, financial, and trade conditions in that country. His report, "Ecuador in 1881," was published as a special message of the President to Congress.

Probably his greatest work was in connection with the Madeira and Mamoré Railway, on which, for ten years, at the invitation of the Government of Bolivia, he devoted his attention. He conducted negotiations with European capitalists and with the Brazilian Government, and if it were possible here to give in detail the incidents of this period of his career it would form an interesting prelude to the history of that great railway which is now under construction, and is a tribute to his foresight and technical capacity.

In later years he took up his residence in London, England, where he associated himself with Argentine railway companies and engaged in literary pursuits, devoting much time to the study of the South American aborigines. As a writer and speaker on subjects connected with his life works, Colonel Church was a recognized authority, and his contributions to the researches of scientific societies are standards

for the student. Although residing in England, his loyal Americanism was always a prominent element in his character. He died in London, on January 5th, 1910, and was buried in Brompton Cemetery.

Colonel Church was twice married; his second wife, who survives him, was the widow of Mr. Frederick Chapman and a daughter of Sir Robert Harding.

Colonel Church was a Companion, first class, of the Military Order of the Loyal Legion, of the United States. For many years he was a member of the Council of the Hakluyt Society, and also of the Royal Geographical Society, having been Vice-President of the latter for a period of four years. It is said that he was "the first man, not a British subject, ever admitted to the honor of a seat in its council." He was a frequent contributor to the Society's *Journal,* and took part in most of the discussions on papers dealing with South American subjects. At the Bristol Meeting of the British Association for the Advancement of Science, in 1898, he was President of the Geographical Section, the subject of his presidential address being "Argentine Geography and the Ancient Pampean Sea." He was also a member of the Royal Historical and of the Royal Anthropological Institute of Great Britain and Ireland.

Colonel Church probably possessed a wider and more complete knowledge of the history, geography, and resources of South America than any other authority. The information he acquired by his own extensive travels in the heart of the continent was supplemented by a lifetime of study of the experiences of other travelers. He followed closely the development of the Panama Canal scheme, and was strongly of the opinion that the construction of the canal was not justified on commercial grounds. A few years ago, when various projects for the building of a new railway across Canada were under consideration, he was actively interested in a scheme for a line to follow a more northerly route than that of the Grand Trunk Railway.

Colonel Church was elected a Member of the American Society of Civil Engineers on November 2d, 1887.

WILFRED EMORY CUTSHAW, M. Am. Soc. C. E.*

DIED DECEMBER 19TH, 1907.

Wilfred Emory Cutshaw was of Scotch descent and was born at Harper's Ferry, Va., now West Virginia, on January 25th, 1838. His father was George W. Cutshaw, a native of Loudoun County, Virginia, who died in 1887. His grandfather was John W. Cutshaw, a Maryland farmer, who was a veteran of the War of 1812. Mr. Cutshaw's mother, Martha J. Moxley, was born in Alexandria, Va., and was of English ancestry.

Mr. Cutshaw, after preparation at home and at a local academy, entered the Virginia Military Institute, at Lexington, from which he was graduated in 1858, with a good knowledge of civil and military engineering. After teaching for one term in an academy in Loudoun County, he became, in 1859, an Instructor in the Hampton Military Institute, and remained there until the spring of 1861, when he resigned to enter the service of the Confederate Army.

In April, 1861, Mr. Cutshaw was made a First Lieutenant, and assigned to a battalion of artillery in the Brigade of General T. J. Jackson. In the spring of 1862 he was made Captain of Artillery; in the fall of that year he became Major, and in February, 1865, he was made Lieutenant-Colonel.

Colonel Cutshaw's war record was exceptionally brilliant. He participated in the operations of General Magruder in the Peninsula, in the summer of 1861, and in the campaigns of Jackson in the Valley, in the spring of 1862, in which he commanded a battery in the battalion of Colonel Crutchfield, taking part in several vigorous engagements. In the Battle of Winchester, in May, 1862, he was severely wounded, a bullet piercing his left knee, and was captured by the Federal forces. He remained a prisoner until April, 1863, when he was exchanged.

A medical examining board having pronounced him unfit for active duty, he was assigned as Acting Commander of Cadets at the Virginia Military Institute, a position which he held until September, 1863, when he applied for readmission into the Confederate Army and was accepted, notwithstanding the fact that his wound was unhealed. He was assigned to duty as Inspector-General of Artillery, Second Corps, Army of Northern Virginia, and participated in a number of battles in 1863 and 1864. In the Wilderness of Spottsylvania, in 1864, while in command of a battalion of artillery, he received a slight wound in his right arm. In February, 1865, he became Lieutenant-Colonel of Artillery, in which capacity he served until April of that year, when, in the Battle of Sailer's Creek, just three days before the surrender at

* Memoir prepared by the Secretary from papers on file at the House of the Society.

Appomattox, he was wounded, and the next morning his right leg was amputated between the knee and the hip. While lying wounded, Colonel Cutshaw gave his final parole, after a record of the most gallant and self-sacrificing service. His name is identified with Cutshaw's Battalion, one of the most serviceable and famous in the artillery arm of the Confederate service.

For a year following the close of the war Colonel Cutshaw engaged in temporary pursuits. In September, 1866, he was appointed Assistant Professor of Mathematics in the Virginia Military Institute, the position held previous to the war by Major, afterward General, T. J. Jackson.

In January, 1868, he was appointed assistant to Mr. Charles P. Stone, Engineer and Superintendent of the Dover Coal and Iron Company, of Henrico County, Virginia. He still continued his connection with the Virginia Military Institute, as Professor of Mathematics, becoming, in 1871, Professor of Civil and Military Engineering, which position he held until the fall of 1873, when he was elected City Engineer of Richmond, Va. The latter position he filled ably for more than thirty-four years.

During his service as City Engineer of Richmond, Colonel Cutshaw saw the city practically rebuilt, and the last traces of the ravages of war obliterated. In this work he encountered many difficulties. The streets and avenues were resurveyed, graded, and paved, and the parks and boulevards laid out. One of his ambitions was to turn every available foot of space into recreation resorts for the public, and especially for the children. During his term of office the water-works system was entirely reconstructed and the mains extended. Perhaps the most notable work of the City Engineer's Department in this period was the construction of the City Hall, which was built by day labor under the personal supervision of Colonel Cutshaw and his assistants.

Colonel Cutshaw held membership in the Royal Arcanum, the Virginia Historical Society, and the Southern Historical Society. For many years he was President of the Alumni of the Virginia Military Institute, and an active member and patron of the Richmond Young Men's Christian Association.

He was married to Mrs. E. S. Norfleet, his first wife, in December, 1876. She died two months later. In January, 1890, he married Miss M. W. Morton, of Richmond, who died in December of the same year. He left no children.

Colonel Cutshaw's policy had always been a comprehensive system of permanent improvement, rather than any temporary provision, and the whole sewerage system built in Richmond during the past thirty years is the result of his scientific study. He was known as a man of iron will, of indomitable perseverance, and of the highest integrity. He was stern, and unbending, and required implicit obedience and

the best that was in his assistants, yet he was always considerate for the unavoidable shortcomings of others, and stood with unflinching constancy by those who were true and faithful.

Colonel Cutshaw lived with Mrs. Calvin Whitely, Jr., his niece, who regarded him almost as her father. He had been ill for several weeks, and his long and eventful life came to a peaceful end on December 19th, 1907.

He was elected a Member of the American Society of Civil Engineers on March 4th, 1891.

CHARLES DAVIS, M. Am. Soc. C. E.*

DIED FEBRUARY 21ST, 1907.

Charles Davis was born in Bridgetown, Bucks County, Ohio, on July 11th, 1837. His mother died when he was eleven years old, and he left home to live on his uncle's farm. He was educated in the county schools and Jefferson College. In 1861, while in his junior year at college, he enlisted in the Army and served during the Civil War.

After his discharge from the Army he entered an engineer corps making surveys in Lawrence County, Pa., and later accepted a position on a corps surveying for the Western Pennsylvania Railroad.

In 1867 Mr. Davis was elected City Engineer of Allegheny, which position he filled for about eight years. During his term the Allegheny parks were laid out, and a sewerage system was put in. He had the general supervision of the Point Bridge.

In 1878 he made the preliminary surveys for the Pittsburg and Lake Erie Railroad, from Pittsburg to Youngstown, Ohio. He also made surveys for other branches of this road to Connellsville, Pa. In the erection of the buildings of the Pittsburg Bessemer Steel Company at Homestead, in 1880, he was Superintending Engineer, and, subsequently, was Engineer for the Monongahela Bridge Company. In 1881 he was elected County Engineer of Allegheny County, Pa. In conjunction with Mr. H. H. Richardson, Architect for the present Court House, he helped to supervise the erection of that building. He held the position of County Engineer for twenty-six years.

In 1868 Mr. Davis was married to Miss Annie V. Cooper, daughter of James Cooper. She died in 1881. They had five children, of whom three survive him: Norman Cooper Davis, Charles W. Davis, and Mrs. Thomas Leggate.

Mr. Davis died, after a brief illness, at his home in Edgeworth, of pleurisy, complicated with other ailments. He had been suffering for some weeks from a severe cold, but his associates did not suspect that his illness was serious.

Mr. Davis was appointed by the soldiers of Allegheny County as a member of the Committee of Ten for the erection of the Allegheny County Memorial. He was active in the work of this committee, and was present at the meeting of the County Commissioners when the selection of the plan, from the ten designs submitted, was made.

He was a member of the Abe Patterson Post, No. 88, of the Grand Army of the Republic; of Encampment No. 1, Union Veteran Legion; of McKinley Lodge, No. 318, F. and A. M.; Allegheny Chapter of the Royal Arch Masons; of Pennsylvania Commandery and Council. He

* Memoir prepared by the Secretary from papers on file at the Society House.

was a Charter Member and a Past-President of the Engineers' Society of Western Pennsylvania, and Treasurer of the Academy of Science and Art, of Pittsburg.

Mr. Davis was elected a Member of the American Society of Civil Engineers on September 15th, 1869.

EDWIN PELEG DAWLEY, M. Am. Soc. C. E.*

DIED OCTOBER 7TH, 1910.

Edwin Peleg Dawley, the son of Peleg and Lucinda W. Dawley, was born in Providence, R. I., on October 1st, 1853. He received his education in the public schools of Providence, and at Brown University, being a member of the Class of 1874. He began his professional career in the Engineering Department for Water and Sewer Construction of the City of Providence, where he served about 7 years.

In 1879 Mr. Dawley accepted the position of Engineer and Superintendent of the Interstate Telephone Company, having charge of the construction of its long-distance line between Boston and Providence. His work and ability brought him in contact with and claimed the attention of the officials of the New York, Providence, and Boston Railroad, who offered him a position in its Engineering Department. He was appointed Assistant to the Chief Engineer in 1882, and subsequently, on the death of the head of the department, was advanced to that office.

In his railroad experience Mr. Dawley showed marked engineering ability in the solution of the many problems involved in the extensive improvements and developments which were undertaken by the Railroad Company during the next decade, notably the improvements in the roadbed and the strengthening of bridges for the constantly increasing and heavier traffic, the abolition of grade crossings, the four-tracking from Pawtucket to Providence, etc., and the passenger and freight terminal facilities at Providence.

In 1892 the New York, Providence and Boston Railroad passed into the control of the New York, New Haven and Hartford Railroad Company, which company retained Mr. Dawley as Division Engineer. In 1903 he was made Assistant Chief Engineer, and in 1905 Engineer of Construction, with offices at Boston and Providence.

Perhaps the foremost of Mr. Dawley's engineering monuments was the design and construction of about a mile of double-track tunnel, and its approaches, through the East Side Hill, in Providence, which afforded direct connection of all the railroad company's electrified lines on the east side of Narragansett Bay, with the existing terminal improvements, and completed the last link in the chain of railroad terminal facilities in Providence, which had been in progress for nearly twenty years. A professional paper on this subject, "The East Side Tunnel and Its Approaches, Providence, R. I.,"† was presented by him to the Boston Society of Civil Engineers in the spring of 1909.

On April 1st, 1909, after 27 years of active service, he resigned his position with the railroad company, and opened an office as Consulting

* Memoir prepared by George B. Francis, M. Am. Soc. C. E.

† *Journal*, Assoc. of Eng. Societies, Vol. XLII, p. 293.

Engineer, in Providence, R. I., where, after a brief illness, he died on October 7th, 1910.

Although he had not been long in private practice, Mr. Dawley had been engaged on several important pieces of work. He was Consulting Engineer for the Commission appointed by the City of Pawtucket, R. I., to work out a plan for eliminating the grade crossings in Pawtucket, plans for which had been completed, but not acted on, at the time of his death.

He had also designed and nearly finished a storage reservoir dam in Smithfield, R. I., for the Woonasquatucket Reservoir Company.

Mr. Dawley was married three times: In 1880 to Mary H. Bliss, by whom he had two children; in 1888 to Florence N. French, by whom he had one child; and in 1906, to Mrs. Maud C. Freeman, who survives him, together with his two sons, Howard and Earl, and his daughter, Mrs. Lewis Ford.

Mr. Dawley was a man of genial disposition, high ideals, unwavering integrity, and exemplary character, who gave himself to his arduous professional duties with tireless energy and unflagging zeal.

He was a member of Harmony Lodge, A. F. and A. M., Calvary Commandery, Knights Templar, and the Scottish Rite.

Mr. Dawley was elected a Member of the American Society of Civil Engineers on April 1st, 1885. He was also a Member of the Boston Society of Civil Engineers.

IRVING TUPPER FARNHAM, M. Am. Soc. C. E.*

Died September 19th, 1908.

Irving Tupper Farnham was born in Deposit, Delaware County, N. Y., on August 21st, 1869. His parents were Charles and Julia (Tupper) Farnham. After a preparatory course at Deposit Academy, he entered the College of Civil Engineering of Cornell University, in 1888, and was graduated in 1892 with the degree of Civil Engineer. He was esteemed highly by his professors, and held the position of Librarian during his last two years in college.

His first engagement after graduation was as a Draftsman with the Elmira Bridge Works. In June, 1892, he entered the office of the late Albert F. Noyes, M. Am. Soc. C. E., City Engineer of Newton, Mass., where he obtained experience in a variety of municipal work, first as Instrumentman on the Cheese Cake Brook drainage improvement, then on surveys for the assessors' block system, and then on the Hammond Pond drainage survey for the Board of Health. In 1894 he took charge of the surveys and construction of the first and second sections of the Newton Boulevard, as Division Engineer, having a field office at Chestnut Hill.

On the completion of this work he was put in charge of the Washington Street widening and the abolition of grade crossings on the north side of the city. In 1898 he conducted the surveys for the South Meadow Brook improvement and made preliminary studies for the abolition of grade crossings on the south side of the city.

In February, 1899, Mr. Farnham was appointed Principal Assistant Engineer of the Massachusetts Highway Commission, which position he filled satisfactorily for a little more than a year.

In April, 1900, after the resignation of Henry D. Woods, M. Am. Soc. C. E., as City Engineer of Newton, Mr. Farnham was appointed his successor. He held this position until his death, on September 19th, 1908.

The following are some of the most important works carried out under his direction: In 1900 the extension of the main sewers along the banks of the Charles River toward Newton Upper Falls, and in 1901 a further extension under the Charles River at Echo Bridge in tunnel to Elliot Street. During that year plans were made for a second section of the covered reservoir on Waban Hill, on which work was commenced but not finished until the following year. In 1902 further sewer extensions were made toward Newton Highlands and Chestnut Hill. Some of these and former sewer extensions involved

* Memoir prepared by the Secretary from information on file at the House of the Society, and from a memoir published by the Boston Society of Civil Engineers.

tunneling under the Cochituate and Sudbury Aqueducts of the Metropolitan Water-Works, and required the greatest care. In 1902, in accordance with an agreement with the Boston and Worcester Railway Company, that company began the widening of about 3 miles of Boylston Street, the City of Newton putting in the drains and inlet basins by day work, all under Mr. Farnham's direction. A small auxiliary pumping plant, for a sewer district at Newton Upper Falls which was below the level of the main sewer, was also designed and built by him. In 1903 the work of abolishing the grade crossings of the Boston and Albany Railroad on the south side of the city was commenced, all the changes in the streets and drains being undertaken by the city. In this work the proper drainage of the depressed tracks made it necessary to lower long stretches of brooks and drains and also make some changes in the sewers. A new concrete bridge over the Charles River at Newton Lower Falls, replacing the Old Red Bridge to Weston, was designed and constructed by Mr. Farnham in 1906.

He was always a student, and the details of all work undertaken in his office received his conscientious and painstaking attention. He was always pleasant with his associates and interested in their welfare.

Mr. Farnham was a Member of the Boston Society of Civil Engineers, and deeply interested in its work. He was a Director of that Society, Clerk of the Sanitary Section, and, at the time of his death, was Chairman of the Committee on Run-off of that section. He spent much time in the study of the question of run-off from sewered areas.

He was also a member of the New England Water Works Association, and of the Massachusetts Highway Association, of which he was President in 1904. The following quotation from the resolutions passed by that Association shows the esteem in which he was generally held:

"A man of character above reproach, an official of most devoted and thorough attention to every detail of his duties, a professional man whose grasp of difficult questions was sure to yield a convincing argument for or against the proposition involved, and whose courage never permitted him to lower the standard he had raised as a governing principle in his work, he had achieved an enviable position as a competent, safe and practical engineer, and there seemed no bar to greater success in his career.

"Too close application resulted in bodily affliction and breaking under the strain, and (we quote the language of his pastor at the funeral) 'sudden darkness came upon his mind, and in that moment of darkness, knowing nothing, he died.'

"His birth, school and college days, as a preparation for his future, and the time of his death are of your official records, and we add now a tribute to his memory, as of a man worthy to be followed in

qualities which make for high purpose, purity of life, perseverance under difficulties, and an abiding trust in the Eternal Wisdom, which made and controls the earthly existence and the destinies of men."

Mr. Farnham was a member of the Congregational Church in West Newton, and much interested in its Sunday-school work. He was married on March 27th, 1892, to Miss Jennie A. Carroll. His wife and four children survive him.

He was elected a Member of the American Society of Civil Engineers on May 1st, 1907.

CHARLES EDWARD GOAD, M. Am. Soc. C. E.*

DIED JUNE 10TH, 1910.

Charles Edward Goad was born in London on March 15th, 1848. He attended the College of Preceptors, in London, passing his final examinations with honors in mathematics. Later he received the degree of Associate of Arts at Oxford University. Until 1869 he was engaged in the building of various public works in England, and in that year he went to Canada. From 1869 to 1873 he was Assistant and then Division Engineer on the Toronto, Grey and Bruce Railway. From 1873 to 1875 he was Locating Engineer and in charge of the drafting office for the land and structure plans, and then Engineer for the contracting company building the Montreal Northern Colonization Railway, afterward the Quebec, Montreal, Ottawa and Occidental Railway.

In 1876 he commenced the compilation of a series of special surveys of Canadian cities and towns for the use of Insurance Companies. In 1877 he became Chief Engineer of the Halifax and Cape Breton Railway, but in the following year found it essential to the success of the system of insurance plans which he had originated to give his whole time to the supervision of that work.

Some idea of the extent to which his system has developed may be gathered from the fact that the surveys now include all the important areas in London, England, from Kingston-on-Thames to Gravesend, fifty-five of the principal cities and towns in the British Isles, several cities on the Continent of Europe, in the "Near East," South Africa, the West Indies, and South America. In Canada more than 1 300 places, from Halifax to Vancouver, have been surveyed and mapped.

In 1909, while engaged on a survey at Valparaiso, Chile, on behalf of the Fire Offices Committee, Mr. Goad had a paralytic stroke. As soon as he could be moved he was taken to England, the voyage being of much benefit to him. After a short stay, he returned to his home in Toronto, with his health so far improved as to encourage the hope that he would be spared for a number of years, but after a journey South and a short stay in Florida, he returned to Toronto in April, 1910, where he died from the effects of a second stroke of paralysis. He is survived by his widow and eight children, three sons and five daughters.

Fire insurance men will remember Mr. Goad as the author of "Fire Plans for Cities," and as the founder of the business now carried on as a Company under the title of Charles E. Goad, Limited. In 1881, in Montreal, he founded the publication, *Insurance Society,*

* Memoir prepared by the Secretary, from information on file at the House of the Society.

but, a few years later, on account of the increasing demands on his time, he transferred it, the paper developing into the *Chronicle,* devoted to banking, insurance, and finance.

Mr. Goad was a man of sterling integrity and indomitable energy, and never happier than when he had difficulties to surmount. Whenever he had opportunity to give any of his time to the public service, notably as a Member of the Executive Committee of the British Fire Prevention Committee, and as an Advisor on the Guild of Civic Art in Toronto, he was unsparing in his efforts for the furtherance of the objects they had in view.

Owing to the wide area of his professional and business interests, he was engaged in almost constant travel, and so did not have the opportunity of building up that large amount of local influence and popularity usual to men of his type who retain one center, but his social acquaintance was very wide, and he was equally popular on both sides of the Atlantic.

To those who were intimate with him, he was endeared by the many fine qualities he possessed. He was entirely lacking in ostentation, and warm-hearted and loyal in his friendship.

His eldest son, Mr. Charles Ernest Goad, who for some years has had charge of the British and Continental surveys, succeeds him as Managing Director of Charles E. Goad, Limited, of London, England, and will also undertake the direction of the Canadian business.

Mr. Goad was elected a Life Member of the Royal Canadian Yacht Club about ten years ago, and was a very ardent supporter of its interests, though he had not the leisure to participate very much in the sport.

Mr. Goad was an active Member of the British Fire Prevention Committee, a Fellow of the Statistical Society of England, and a Member of the London Chamber of Commerce. He was also a Member of the Engineers' Club of Montreal, the Engineers' Club of Toronto, the Engineers' Club of New York, the Toronto Club, and the Canadian Society of Civil Engineers. He was elected a Member of the American Society of Civil Engineers on September 7th, 1881.

DANIEL FARRAND HENRY, M. Am. Soc. C. E.*

DIED MAY 13TH, 1907.

Daniel Farrand Henry was born in Detroit, Mich., on May 27th. 1833. He was the only child of Dr. Stephen Chambers Henry and his second wife, Charlotte (Farrand) Henry. His father was a native of Pennsylvania, who, after his graduation from the University of Pennsylvania, in 1809, moved to Detroit where he began the practice of medicine. He served as an Army Surgeon during the War of 1812, being taken prisoner at the surrender of Detroit by General Hull. He was also active in local and State affairs. His mother was a daughter of Daniel Farrand, one of the Judges of the Supreme Court of the State of Vermont.

On his father's side, Mr. Henry was descended from Robert Henry who, with his family, settled in Chester County, Pennsylvania, in 1722. His great-grandfather, William Henry, who had moved to Lancaster, Pa., served as Armorer under Generals Braddock and Forbes in the expeditions against Fort Duquesne. William Henry took an active part in local and State affairs, holding many positions of trust. During the War of the Revolution he was appointed Assistant Commissary General of the United States, and served two terms (1784-1786) as a Member of the Continental Congress. He was a Member of the American Philosophical Society, a Charter Member of the Society for Promoting Agriculture, and one of the Founders of the Juliana Library Company, of Lancaster, Pa. Mr. Henry's grandfather, John Joseph Henry, served under General Benedict Arnold in the campaign against Quebec, being captured and afterward paroled. In 1793, he was appointed President Judge of the Second Judicial District of Pennsylvania, holding this position until a year previous to his death.

His father died when Mr. Henry was only one year old. As he was a delicate child, he did not attend school, but was taught the primary branches by his mother, who was well qualified for the task. He made such rapid progress under his mother's tuition that he was soon able to read books of a character much above the capacity of boys of his age, and as much of his time was spent indoors, on account of his health, he found his chief pleasure in books.

When he was ten years old, Mr. Henry was sent to Canandaigua Academy, where he remained only a short time. He then attended the old Capitol School, in Detroit, and from there he was sent to school at Newark, Ohio, and then to Canandaigua Academy. When he was sufficiently advanced to begin his higher studies, he attended a scientific

* Memoir prepared by the Secretary from information supplied by Mr. Henry's nephew, William L. Henry, Esq., and from papers on file at the House of the Society.

school in Providence, R. I., where he made rapid progress, his proficiency in the higher mathematics being phenomenal. He seemed to accomplish by intuition what most people attain only by laborious effort and persistent study.

He was a member of the first class of Sheffield Scientific School of Yale University, and was graduated with distinction in 1853.

Upon his return to Detroit, in 1853, Mr. Henry was appointed to a position in the United States Lake Survey, under Lieutenant W. F. Reynolds, U. S. A., who was then in charge of the Survey of the Northern and Northwestern Lakes for that District. He continued in this work until 1871, holding various important positions, under Lieutenant Reynolds and several of his successors. In 1856, he was chief of a shore party; from 1861 to 1867 he was in charge of the triangulation and the measurement of primary bases; from 1868 to 1871 he superintended the measurement of the outflow of the Lakes; and for about six years he was also in charge of the Meteorological Department.

During the seventeen years of his connection with the Government Survey of the Northern and Northwestern Lakes, Mr. Henry accumulated valuable information as a result of his untiring observations and experiments, much of which may be found in scientific publications. His observations on the overflow of the Lakes and on the sudden rise and fall of their levels, are regarded as the highest authority on the subject, and have been the cause of much discussion. It was in connection with these observations that he invented the telegraphic current meter which has come into general use for velocity measurements and for which, together with the flexible inlet pipe, invented for use at the Detroit Water-Works, he was granted a medal at the Centennial Exposition in 1876. His book on the "Flow of Water in Rivers and Canals" has received the highest praise.

Mr. Henry took an active interest in affairs outside of his work. Being an enthusiast about physical exercise, he was one of the organizers of the Detroit Gymnasium in 1856. He was also a member of the Young Men's Society, before which he frequently delivered scientific lectures. He was also one of the organizers of the Detroit Scientific Association, serving as one of its Curators for several years.

In 1871, Mr. Henry became a partner in the Chicago Seed Company, remaining in the seed business until 1873, first in Chicago and afterward in Detroit. His company was burned out in the great Chicago fire on October 8th and 9th, 1871, by which Mr. Henry lost, besides his business, a large portion of his library, much of which could never be replaced.

In 1872 he was appointed Chief Engineer of the Detroit Water-Works, continuing in this position until 1878. During this time the

present pumping works above the city were constructed, and it was for use at this plant that Mr. Henry invented the flexible inlet pipe already mentioned.

In 1880, he went to the Upper Peninsula of Michigan as Consulting Engineer for the Detroit, Mackinac, and Marquette Railroad. His first work was in connection with observations on the ice in the Straits of Mackinac. He also made a canoe trip from Lake Superior to Lake Michigan in order to examine the drainage of the swamp through which the railroad was to pass.

During his residence on the Upper Peninsula Mr. Henry laid out nine villages and stations for the Peninsular Land Company; he was engaged for some time at Sault Ste. Marie, in the employ of a water-power company; and designed a new system of water-works for the city; he was the Architect of the present Chippewa County Court House; and for some years was engaged in private practice.

About 1890 Mr. Henry returned to Detroit, where he was in private practice as a Consulting Engineer until his death on May 13th, 1907. One of his last works of engineering was as Projector and Chief Engineer of the St. Clair and Erie Ship Canal, which, however, was never built.

Mr. Henry had never married. He had taken all the Masonic degrees, and was a Member of the Veteran Corps of the Detroit Light Guards, which he had joined in the later Fifties.

Mr. Henry was elected a Member of the American Society of Civil Engineers on July 7th, 1875.

GEORGE ANTHONY LEDERLE, M. Am. Soc. C. E.*

Died March 27th, 1905.

George Anthony Lederle was born, of German parentage, in Detroit, Mich., on September 4th, 1858. His father was, for many years, in the United States Lighthouse Service, engaged in constructing lighthouses.

Mr. Lederle entered the University of Michigan in 1877, and was graduated in 1881 as a Civil Engineer. After leaving the University, he was engaged for several years with the late George S. Morison, Past-President, Am. Soc. C. E., on bridge construction. During this time he was in charge of the construction of the Union Pacific Bridge across the Missouri River, at Omaha, Nebr., the bridge across the Willamette at Portland, Ore., and the viaduct at Morent Mountain.

George B. Christie and Jesse Lowe, Members, Am. Soc. C. E., having organized the firm of Christie and Lowe, to engage in general contracting, invited Mr. Lederle to join the firm. After considering the proposition for a year, he decided to become a partner, which he did in 1892. During his connection with this firm, Mr. Lederle had personal charge of some of its most important contracts. When the contract to build the jetties at the Southwest Pass was awarded to this firm in 1903, he went to New Orleans, La., and took charge of the actual construction. He was engaged on this work when he died, after a short illness, on March 27th, 1905.

Mr. Lederle was not married. He was a Member of the Western Society of Civil Engineers and of the Louisiana Engineering Society. He was also a Member of the Delta Kappa Epsilon Fraternity.

He was known all over the United States as a civil engineer of renown, and in an obituary notice, dictated by his partners and published in *The Daily Picayune* of New Orleans, La., it is stated that:

"Mr. Lederle was ever of a quiet demeanor. He was a man who had little to say, but who meant what he said. Of strong convictions, of strong likes and dislikes, he was ever kindly and gentle. Those who knew him, knew him only to love him, and he had friends by the hundreds in all parts of the country. The two surviving members of the firm who worked with him through so many years, particularly feel the loss, for few knew him better or loved him more than these two."

Mr. Lederle was elected a Junior of the American Society of Civil Engineers on May 2d, 1883, and a Member on October 6th, 1886.

* Memoir prepared by the Secretary from papers on file at the House of the Society.

EDMUND DORMAN LIBBY, M. Am. Soc. C. E.*

DIED APRIL 24TH, 1903.

Edmund Dorman Libby was born in Lyman, Me., on November 1st, 1851. He received his early education at the public schools of Jaffrey, N. H., to which place his parents had removed in 1867. In 1875 he was graduated from Kimball Union Academy, at Meriden. After his graduation from Dartmouth College, with the degree of A. B. in 1879, he entered the Thayer School, and in 1882 received his degree as Civil Engineer.

As a student in the Thayer School, Mr. Libby was unusually mature for his years. With a classmate he mastered the contents of Church's "Descriptive Geometry" within a few weeks of his entrance examinations, and passed a searching examination in the subject.

During his first vacation Mr. Libby was employed as Inspector of dredging on harbor work under the charge of a United States Engineer Officer, and discharged the duties so faithfully that he received the maximum pay allowed for such service. After his graduation in 1882 he entered the employ of the Government as Assistant Engineer on the Mississippi River improvement, with headquarters at St. Louis, Mo.

In 1887 he left the Government service to enter the employ of the Edgemoor Bridge and Iron Company, of Wilmington, Del., where he remained for one year. In 1889, he entered the service of the New York, New Haven and Hartford Railroad Company, with headquarters at Providence, R. I. He remained with this company until 1894, when he returned to the Government Service and was appointed Assistant Engineer on the works for the improvement of the Mississippi River, below St. Louis, which were being done under the direction of the United States Engineer Office. While in this position Mr. Libby had, for some years, responsible charge of the extensive operations for shore protection and regulation of the channel by dikes, mattresses, etc., and commanded large forces of men, towboats, barges, etc.

In November, 1901, Mr. Libby was obliged to give up his work on account of failing health. He spent that winter in Denver, Colo., hoping that the change of climate would prove beneficial. This hope was not realized, however, and in June, 1902, he returned to Concord, N. H., where he died on April 24th, 1903.

In June, 1887, Mr. Libby was married to Miss Emma O. Curtice, of Concord, N. H., who died in 1902. He was a Knight Templar, a Member of the Ancient Order of United Workmen, and of the Independent Order of Redmen.

In a brief summary of some personal reminiscences by an associate on the Mississippi River work, it is stated that Mr. Libby was a very

* Memoir prepared by the Secretary from papers on file at the House of the Society.

reserved man, working at times all day without exchanging a word with others in the same office. He was careful and conscientious almost to excess, working overtime and late into the night in order to accomplish work which he would not entrust to others. He was an excellent draftsman and a skilled mechanic, and owned a large and valuable collection of fine tools of various sizes and styles, which afterward found a ready sale at appraised value.

Mr. Libby was elected a Member of the American Society of Civil Engineers on May 6th, 1885.

JOHN EGBERT McCURDY, M. Am. Soc. C. E.*

Died December 14th, 1908.

John Egbert McCurdy was born near Quitman, Miss., on June 10th, 1861. His parents moved to Lawrence, Kans., in 1864. As he was a very delicate child, his parents sent him to Boston, in 1866, where he was placed under the care of a specialist; at the end of two years, however, he returned to his home with his health but little improved.

He was educated at the Lawrence High School and Kansas State University where he spent three years. During his college years he was engaged in various land and town surveys.

On leaving college he served for two months as Transitman on location surveys for the Carbondale Extension of the Kansas Pacific Railway, and then as Topographer, Office Engineer, and Assistant Engineer, on the Kansas City, Springfield, and Memphis Railway, first on surveys, and finally on construction. For a few months in 1883 he was engaged in private practice in El Paso, Tex. He then went to Mexico as Topographer on surveys for the Mexican Central Railway. From 1884 to 1887 he served in the Operating Department of the latter railway, and was afterward appointed Division Engineer on the Guadalajara Extension.

From July, 1888, to November, 1890, Mr. McCurdy was employed as Locating Engineer on the Mexican Southern Railway, then, until June, 1892, as Division Engineer in charge of the construction of the Tomellin Cañon Division, and was then engaged in reconnaissance surveys for that railway until January, 1893.

From January, 1893, to May, 1894, he was in private practice in the City of Mexico, reporting on water-works and railways. During this period he made surveys for the Ferrocarril de Guadalupe to Zacatlan, and, as Manager and Chief Engineer, located the Ferrocarril del Cazadero á Solio, which was partly graded when work was suspended for financial reasons.

In June, 1894, he was appointed Resident Engineer on the Chihuahua Water-Works, for which he conducted the surveys, design, and construction.

Mr. McCurdy was interested in several mines in the States of Chihuahua, Durango, and Oaxaca, and carried out considerable contract work on the construction of buildings, sewers, and irrigation projects. At the time of his death he had just completed the construction of the Oaxaca and Oriental Railway.

* Memoir prepared by the Secretary from information supplied by J. W. Miles, M. Am. Soc. C. E., and from papers on file at the House of the Society.

Mr. McCurdy was one of the best known engineers in Mexico, and, in the design and execution of work, was considered a very capable man. His opinions were eagerly sought, both by engineers and contractors, when difficult problems were encountered.

He was a Member of the American and Jockey Clubs, of the City of Mexico.

He died in the American Hospital, in the City of Mexico, on December 14th, 1908, from the effects of a surgical operation. He is survived by two sisters, Mrs. Mais, of Texas, and Miss F. Eleanor McCurdy, of Lawrence, Kans.

Mr. McCurdy was elected a Member of the American Society of Civil Engineers on April 1st, 1896.

THOMAS McKEOWN, M. Am. Soc. C. E.*

Died June 7th, 1904.

Thomas McKeown was born in Southampton, England, in 1844. He was taught surveying, leveling, and drawing on the Ordnance Survey of Great Britain, at Southampton. From 1864 to 1869 he was engaged, as a subordinate, in making surveys and plans of defensive positions in Canada for the Imperial Government. He was then employed on the construction of the Wellington, Grey, and Bruce Railroad, as Assistant Engineer, from June, 1871, to December, 1872, when he was made Resident Engineer in local charge of the work until December, 1873. During part of this time (1870 to May, 1871), he was also engaged on surveys and plans of the City of Montreal for municipal and insurance purposes.

For six months in 1874 Mr. McKeown was Assistant Engineer on location for the Hamilton and North Western Railway. From January to May, 1875, he located the entire line (70 miles) of the London, Huron, and Bruce Railway, running through a difficult country. He was then appointed Resident Engineer on the construction of the last 18 miles of this road where he remained until December, 1875.

In January, 1876, he was appointed Chief Engineer of the Hamilton and North Western Railway, which position he retained until 1881, directing the location of the various sections, and having charge of the maintenance of way, until the road was completed in 1879. From 1879 to 1881 he was in entire charge of the maintenance of way.

In 1881 and 1882, Mr. McKeown was General Superintendent of the Detroit, Mackinac, and Marquette Railroad, and from January to September, 1883, he was engaged as Contractor on the construction of the Marquette, Houghton, and Ontonagon Railroad.

In 1884, he went to England, and, until 1890, traveled extensively there and in France. On his return to the United States in 1890, he settled in Buffalo, N. Y., where he engaged in the retail trade of contractors' supplies, etc.

Mr. McKeown became a member of the firm of McKeown and Stowell, which, in 1891-1893, built the Norwalk Avenue and other large sewers in Buffalo. In payment for this work, the firm was obliged to take sewer bonds, which it had to discount at from 25% to 30%, and was compelled to make an assignment.

The next two years (1894-1896) were spent by Mr. McKeown in surveying and in building small sewers. He then became a member of the firm of Smith and McKeown, and, in 1897-1898, built the substructure of the Chicago Street Viaduct. On the death of Mr. Smith,

* Memoir prepared by the Secretary from information furnished by W. A. Haven, M. Am. Soc. C. E., and from papers on file at the House of the Society.

in 1898, the finances of the firm were left in such shape as to embarrass Mr. McKeown seriously. From 1899 to 1902, he was engaged in the construction of sewers and cement walks. In 1902 the firm of McKeown and Johnson was organized, and, during 1902-1904, built the substructures of the Louisiana Street Viaduct, the Perry Street Viaduct, the South Buffalo sewer, and the Lockport Bridge.

On June 2d, 1904, Mr. McKeown contracted pneumonia, and died at his home in Buffalo, N. Y., five days later.

In 1884 Mr. McKeown was married to Miss M[illegible] E. Tempany of London, England. He is survived by his wife and three daughters.

Mr. McKeown was elected a Member of the American Society of Civil Engineers on December 3d, 1879.

JOHN JAY McVEAN, M. Am. Soc. C. E.*

DIED AUGUST 21ST, 1910.

John Jay McVean was born at Darien, Genesee County, N. Y., on June 13th, 1850. He was the second son of John and Isabella McVean, and a descendant in direct line from the Clan McVean of Scotland.

His early education was received in the public schools and at the Free Academy of Rochester, N. Y., and the Rural Seminary at East Pembroke, N. Y. In the fall of 1869 he entered Cornell University, where he studied for three years.

Mr. McVean began his engineering work in the summer of 1872 on the survey for the Rochester and State Line Railroad, and he remained with this Company until the work was stopped by the panic of 1873. During the greater part of 1874 he was Assistant Engineer for the Erie Railroad, on second-track work between Hornellsville and Corning, N. Y. In 1875 he was employed as Assistant Engineer on the location and construction of the Rochester, Hornellsville and Pine Creek Railway. In 1876 he went to Michigan and served two years as City Engineer of Lansing. In 1878 he entered the service of the Detroit, Lansing and Northern Railroad, of which road he was made Chief Engineer in 1881. In 1889, he was also appointed Chief Engineer of the Chicago and West Michigan Railway.

Mr. McVean held these positions until 1900, when failing health obliged him to give up active work. Partially recovering his health in 1905, he engaged, until his last illness, in consulting practice in his home city, Grand Rapids, Mich. In 1909 he was chosen by that municipality and the railroads concerned, to prepare plans for a comprehensive system of grade separation throughout the city.

Mr. McVean was an able executive, an engineer who combined theory with common sense, a man of sterling integrity and lovable disposition, and a chief under whom loyal service was a pleasure.

During the last twelve years of his life, Mr. McVean suffered intensely and constantly from arthritis, but bore his affliction with a courage and patient endurance rarely seen.

In 1879, he married Miss Rachel Shankland at Ellicottville, N. Y., who, with a son and a married daughter, survives him.

Mr. McVean was elected a Member of the American Society of Civil Engineers on September 3d, 1884, and served as a Director of the Society from 1898 to 1900. He was also a Member of the Western Society of Engineers, and of the American Railway Engineering and Maintenance of Way Association, and, from 1894 to 1897, he served as a Member of the Board of Public Works of Grand Rapids, Mich.

* Memoir prepared by Job Tuthill, M. Am. Soc. C. E.

WILLIAM ANSON PEARSON, Jr., M. Am. Soc. C. E.*

DIED MAY 26TH, 1908.

William Anson Pearson, Jr., son of W. A. and Margaret Pearson, was born on July 29th, 1855, at Athens, Bradford County, Pa., where he received his early education. He was graduated from the High School at Sayre, Pa., in 1870.

He served his apprenticeship as a machinist in the shops of the Delaware, Lackawanna, and Western Railroad, in Scranton, where his exceptional ability soon won him the position of foreman.

He served in the Motive Power and Civil Engineering Departments of the Union Pacific Railroad, in Omaha, Nebr., for three years. In 1879 and 1880 he was Master Mechanic for the Virginia-Trukkey Railroad at Carson City, Nev., and from 1880 to 1884 was Superintendent of Construction on the Comstock Lode, in charge of the connection of all the mines with the Sutro Tunnel.

In 1884 he moved to Boston, Mass., and practised as a Consulting Engineer for two years. Then for a year he was Superintendent of the Marine Engine Department of the Dickson Manufacturing Company, at Scranton, Pa. From 1887 to 1893 he was with the Boies Steel Wheel Company, at Scranton, first in charge of design and construction, and later as Manager of the plant.

In 1893 Mr. Pearson became associated with the General Electric Company, with headquarters at Schenectady, N. Y., and from that time until his death was Chief Engineer, in charge of the design and construction of all buildings, steam and water mains, railroads, sewers, yards, etc. The buildings at the various plants of this company bear witness to his ability.

Mr. Pearson was greatly beloved by his associates because of his thorough honesty in everything. In the latter part of his life, it was his aim to help young men in their upward course in the world. He was very eager and ready to assist wherever he could, and many enjoyed his help and inspiration.

Mr. Pearson was an active member of the Masonic Order, and at the time of his death was a member of St. George's Lodge, No. 6, F. and A. M.; St. George's Chapter, No. 157, R. A. M., and St. George's Commandery, No. 37, Knights Templars. He was also a Member of the American Society of Mechanical Engineers, a Member of the Royal Arcanum, and an active worker and officer of the First Presbyterian Church of Schenectady, N. Y.

In 1885 he married Miss Mary Burns, who died a year later, and in 1888 he married Miss Helen Franklin, who died in 1896. He is

*Memoir prepared by the Secretary from information furnished by L. C. Reynolds, Assoc. M. Am. Soc. C. E., and from papers on file at the House of the Society.

survived by one sister, Mrs. Lucy A. Cordeaux, and her daughter, Miss Helen Cordeaux, of Schenectady, N. Y.

Mr. Pearson's health failed continuously for about a year previous to his death, but his enjoyment of his work was such that it was with difficulty that he was persuaded to leave it. However, he decided to take a trip to Virginia and possibly abroad, with the expectation of then resuming his work, but he had just started upon his journey when he was taken seriously ill and immediately returned to his home in Schenectady. He had been home but a few hours when he died.

Mr. Pearson was elected a Member of the American Society of Civil Engineers on September 6th, 1905.

STILLMAN WILLIAMS ROBINSON, M. Am. Soc. C. E.*

DIED OCTOBER 31ST, 1910.

Stillman Williams Robinson was born on a farm near South Reading, Vt., on March 6th, 1838. His early life was that of a country boy, but he had such a love for mechanics that he served a four-year apprenticeship as a machinist. In this way he earned the money to defray the expenses of his early education and his preparation for college.

In 1860 he entered the University of Michigan, making the journey from his home principally on foot, and meeting his expenses by working as a machinist. In 1863 he was graduated from that university as a Civil Engineer, having supported himself, while in college, as an instrument-maker. He was particularly skillful in graduating thermometers, and this led to his first invention, made while in college, a machine for graduating such instruments.

After his graduation, Mr. Robinson entered the Government service as Assistant Engineer in the United States Lake Survey. He remained in this position until 1866, when he was appointed Instructor in Engineering at the University of Michigan. In 1870 he accepted the chair of Mechanical Engineering and Physics in the Illinois Industrial University (now the University of Illinois), where he established the first Department of Mechanical Engineering in the United States. In 1878 he became Dean of the College of Engineering. His versatility is illustrated by the fact that, while he was at the college, he designed and constructed the tower clock now furnishing time there.

In 1878 he was called to Ohio State University as Professor of Physics and Mechanical Engineering, and held this position until 1881, when the chair was divided and he became Professor of Mechanical Engineering. He held this position until 1895, when he resigned in order to devote his time to his extensive professional interests. In recognition of his distinguished services as a scientific inventor, investigator and writer, the Ohio State University, in 1896, conferred on him the degree of Doctor of Science, and, in 1899, elected him Emeritus Professor of Mechanical Engineering.

Professor Robinson possessed great originality and inventive genius, having secured about forty patents, many of which were fundamental and of great value. His inventions were the results of study, based on scientific research and mathematical investigation, and were designs rather than accidental discoveries. He was also the author of books and papers, and these are marked by originality and thorough research. In 1892, a paper entitled "Red Rock Cantilever Bridge,"† written by

* Memoir prepared by the Secretary from material furnished by a Committee of the Faculty of Ohio State University.

† *Transactions*, Am. Soc. C. E., Vol. XXV, p. 662.

Samuel M. Rowe, Stillman W. Robinson, and Henry H. Quimby, Members, Am. Soc. C. E., was awarded the Thomas Fitch Rowland Prize. On the discovery of the Ohio gas fields, the problem of measuring the volume of flow, having been referred to Professor Robinson, was solved by him by his brilliant application of the Pitot tube, which resulted in the methods now generally used.

He had always a great interest in education, and, in 1890, organized an association of teachers of mechanical engineering, from which, in 1893, was evolved the present Society for the Promotion of Engineering Education. His retirement did not affect his interest in and love for the University. At various times he made valuable donations to the equipment of the Department of Mechanical Engineering, and finally established on a permanent foundation the Robinson Fellowship in Engineering.

Professor Robinson was an indefatigable worker, there being no limit to his enthusiasm and ambition in his profession. He was modest and retiring, never claiming credit for himself, though most generous in according it to his associates. He had a deeply sympathetic and very kindly nature, and was inflexible in his devotion to duty and his principles of integrity and honor. The work and success of those around him, both colleagues and students, interested him greatly, and he imparted to them his own enthusiasm, encouraging, stimulating, and rewarding them. His memory and influence will long be felt in the lives of those who follow after him, and who have taken up his work where he left it.

On his death the following action was taken by the Faculty of the Ohio State University:

"Resolved: By the University Faculty that in the death of Professor Stillman W. Robinson the University loses one whose great and loyal service has left a deep impression on the history and development of this Institution, the Faculty an associate whose ability and scholarship has earned him a national reputation, and a friend whose personal influence has helped those around him in their work and professional advancement.

"That we extend our deep sympathy to his widow and family in their bereavement and sorrow.

"Resolved: That these resolutions be spread upon the minutes and a copy sent to the family.

"N. W. LORD,
"EDWARD ORTON, JR.,
"WM. T. MAGRUDER,
"Committee."

Professor Robinson was elected a Member of the American Society of Civil Engineers on January 2d, 1884.

ARCHIBALD ALEXANDER SPROUL, Jr., M. Am. Soc. C. E.*

Died April 26th, 1910.

Archibald Alexander Sproul, Jr., a son of Archibald Alexander Sproul, was born on January 10th, 1868, near Middlebrook, Augusta County, Va., where he resided, until he reached his majority, at the old family home first settled by the Sprouls in 1745. His parents were of the Scotch-Irish stock of the region, and Presbyterians.

The son, like the father, was educated at Washington College, Lexington, Va. (now the Washington and Lee University), and was graduated in June, 1890, when he took up his profession as Civil Engineer. He was one of the most popular men in the University both with his fellow-students and in the society of the town.

Immediately on his graduation Professor D. C. Humphreys, his Instructor, who was also Engineer for the Grottoes Company and engaged in laying out a town to be known as Shendun, organized what he called "The College Party," composed entirely of college students, and put Mr. Sproul in charge. His work in this position was more than satisfactory, and was considered by Professor Humphreys to be the best he had ever known to be done by a boy, fresh from college and without any previous practical experience.

For a short time after this Mr. Sproul was engaged in other lines than Civil Engineering, having charge, for some time, of a match factory in the region of his home.

The Official Survey of Roanoke, Va., having been ordered by the Court, was undertaken in 1891 under the direction of Mr. George P. Wood and the City Engineer, Mr. William M. Dunlap. Early in the following year Mr. Sproul sought and obtained a position with the Survey, and remained with it until June, 1893, when he resigned to take charge, as Assistant Engineer, of one of the parties organized for the Topographical Survey of the City of Baltimore, of which General Henry T. Douglas was Chief Engineer. He left on October 31st, 1895, on the practical completion of the field work of this important and well-known survey. Both the surveys mentioned were made by precise methods practically applied, and Mr. Sproul's assistance in obtaining the very satisfactory results was much appreciated by his superior, Mr. Wood, who often refers to him in the warmest terms.

In March, 1896, he accepted a position as Assistant Engineer in the Bureau of Highways, Borough of the Bronx, New York City, which he retained for more than four years. This covered a period

* Memoir prepared by David C. Humphreys and Robert Ridgway, Members, Am. Soc. C. E.

of great development in the highway system of the Borough, and he was closely identified with its work of construction.

In June, 1900, Mr. Sproul entered the service of the Rapid Transit Railroad Commission, in New York City, and was placed in responsible charge, as Assistant Engineer, of the heavy section of subway construction known as "6B," on Broadway, between 82d and 104th Streets, remaining there for more than five years, until the work was completed and the road in successful operation. This was one of the most important sections of construction on the line of the Manhattan-Bronx subway, and included the complicated details of the junction of the Broadway and Lenox Avenue branches above the 96th Street Station. The estimated cost of its construction was about $3 000 000.

The Board of Water Supply, provided for by an act of the Legislature in 1905, for the purpose of securing an additional supply of water for New York City, was appointed in June, 1905. In September of that year Mr. Sproul took a position as Assistant Engineer with that Board, and when the organization of the Engineering Bureau was permanently effected, was, on April 15th, 1907, made Division Engineer of the Peekskill Division of the Catskill Aqueduct, which is designed for a capacity of 500 000 000 gal. daily. This Division, 13 miles long, is on the east side of the Hudson River, and extends from the vicinity of the Village of Cold Spring south to the Croton watershed, traversing the rough and historic country of the Hudson Highlands. In addition to about 8 miles of open-cut work, it includes three tunnels, one more than two miles long, as well as three steel pipe siphons, aggregating about two miles in length. The locating of the line was done under Mr. Sproul's personal direction, and was so intelligently and vigorously prosecuted that in a little more than a year after he took charge the difficult work was accomplished and the entire division, except the three siphons, was ready to be placed under construction. In the spring of 1907 a contract of an estimated value of more than $4 100 000 was let for the work, exclusive of the siphons, Mr. Sproul remaining in charge of the construction until May 9th, 1909, when he resigned to become Managing Engineer for the Receivers of the original contractor, who were then carrying on the work. This position he occupied until he resigned on March 1st, 1910.

While on a visit to his old home in Virginia during the following month, he had an attack of pneumonia, and, after a short illness, died on April 26th, 1910. His widow, who was Miss Mary I. Cotton, of New York City, to whom he was married on October 12th, 1897, and a son nine years of age, survive him.

A man of broad views and deep convictions, of flawless rectitude and high attainments in his professional work, he was clear in his perception of his duties, and fearless in carrying out without prejudice what he believed was right. He was discreet in his friend-

ships, and having selected his friends, no one was more loyal to them than he. More than most men he was beloved and respected for his many amiable and sterling qualities by those who had the privilege of knowing him well, and the profession is poorer by reason of his death.

Mr. Sproul was elected a Member of the American Society of Civil Engineers on May 1st, 1907.

GEORGE HUNTINGTON THOMSON, M. Am. Soc. C. E.*

Died February 7th, 1910.

George Huntington Thomson was born in Syracuse, N. Y., in 1847. He first engaged in engineering work in 1865 when he became Assistant Engineer on the Oswego and Syracuse Railroad (now part of the Delaware, Lackawanna and Western Railway), in which position he remained nearly two years. He then went to New Orleans, La., where he filled a position as Assistant Engineer on Government work for about two years, and later became Resident Engineer on the New Orleans, Mobile and Texas Railroad. He was with the latter company some four years, being located in Louisiana and Mississippi, and was finally promoted to a position in charge of yards, stations, and structures.

From the South he went to the New York Central and Hudson River Railroad, and was connected with that road for twenty-one years, first as Assistant Engineer on track work, then as Engineer of Bridges, and later as Consulting Bridge Engineer. After leaving the service of the New York Central as Bridge Engineer in 1893, Mr. Thomson engaged in a consulting and contracting engineering partnership in New York City, in which he continued until 1900. During this period he was at one time Chief Engineer of the Metropolitan Traction Company, which proposed the construction of an elevated railway line in New York City, a project which was ultimately abandoned. Among his clients as Consulting Bridge Engineer were the New York Central and Hudson River, the Central Vermont, the St. Lawrence and Adirondack, and the Mohawk and Malone Railroads, and at one time he was retained on the construction of the Williamsburg Suspension Bridge over the East River between New York City and Brooklyn.

In 1900 the engineering partnership was dissolved, after which, his health being broken, due largely to severe injuries received in a railroad accident, he did little active work for several years. In 1907 he entered the service of the New York State Engineering Department in a field position on the New Barge Canal. The active, outdoor work greatly improved his health, and gave him restored confidence and vigor. He received several promotions, being placed, after about two years' service, in charge of the execution of one of the contracts on the Oswego Canal, in the vicinity of his first engineering work. His early acquaintance with the locality, combined with his ability and experience, made him of great value to his employers in the settlement of water rights and similar problems involved in the construction of the

* Memoir prepared by A. W. Carpenter, M. Am. Soc. C. E.

new canal. It seems, indeed, a pity that this reawakened career of activity could not have been continued and crowned with still greater success. The all-wise Providence ruled otherwise, however. The injuries received in the railroad accident many years before (1892) were so serious that Mr. Thomson never fully recovered, and they finally caused his death, which occurred on February 7th, 1910, at his home in Syracuse, N. Y.

During the later years of his service with the New York Central and Hudson River Railroad, and in his following consulting practice, Mr. Thomson gained great prominence as a bridge engineer. He continued the advocacy of riveted truss construction, which had been especially developed on the New York Central Railroad, and on that road, in 1888, he introduced the ballasted trough floor, this being its first use on American railways. This floor was in the form of rectangular troughs, and Mr. Thomson used it very extensively in the design of bridges on the New York Central, the St. Lawrence and Adirondack, the Mohawk and Malone, the Central Vermont, and the Rutland Railroads. He also developed a type of truss, known by his name, of which a number were built on the New York Central and other railroads and are still in service. This truss consists of a double Warren system, with subdivided panels and all connections riveted. He designed plate girders of lengths that must have seemed bold for their time, there being one span of 115 ft. 6 in., built in 1890 and still in service, and many built in the early Nineties were more than 100 ft. long.

Mr. Thomson was early in adopting steel as a substitute for iron in bridge construction; he examined very carefully into its manufacture, and prepared specifications for acid open-hearth steel for structural work, which were remarkable for their scope and thoroughness. They called for a grade of material which probably is not excelled by the best product of to-day. A prominent bridge engineer, who knew him and his work well, writes: "There were few bridges built in those times which had as good material in them as those which he put up."

The largest and most striking structures designed by Mr. Thomson or under his direction are the Park Avenue Viaduct and the Harlem River four-track draw-bridge of the New York Central and Hudson River Railroad in New York City. The former is a four-track elevated structure of plate girders with a ballasted trough floor, about 1¼ miles long, and the latter is probably the heaviest and perhaps the most important draw-span in the world, being 398 ft. long, carrying four tracks on a solid trough floor (not ballasted), containing 2 200 tons of steel, and controlling the traffic of the railroad company into its New York terminal.

Mr. Thomson, as before suggested, was a strong advocate of riveted *versus* pin-connected trusses, and he may be said to have been a violent

opponent of the latter. He designed and built riveted lattice trusses up to 230 ft. span (single-track, Bridge No. 31, Central Vermont Railroad, Thomson-type trusses), advocated their construction to 250 ft. span, and is said to have designed a single-track riveted truss of 500 ft. span, which, however, was not built. Examples of his designs have been reproduced and commended in prominent textbooks on bridge design, and many were described and illustrated in the technical magazines of his time.

In his designing, Mr. Thomson gave a great deal of thought to the action of metal in bridge members under stress, "structural motion," as he called it, and he attempted to proportion bridge members with such action in view. He studied closely the action of bridges under live loads; he was not satisfied to follow the ordinary "strain sheet" practice, but sought to provide additional methods of gaining rigidity and permanence, accompanied with economy, in structures. Some of the important things he recognized in the early Nineties were the effect of time in loading members, and the unequal distortion of members of equal section but varying length.

In his "structural motion" theory, which was given considerable attention at one time, he recognized the distortion of members under stress as changing the conditions of static computations, and considered the effect of frequency of loading to be, even with moderate live loads, a leading factor, as well as the application of the maximum live load. Vibratory effects were also considered. This theory, which Mr. Thomson did not develop as clearly as might be desired, did not lead directly to any well-defined rules or specifications for designing of which there is any record, but it appears to have in it the elements of the present impact and secondary stress conceptions, which it probably assisted to develop. It shows, at least, Mr. Thomson's originality of thought, and his characteristic of searching deep below the surface.

Mr. Thomson was known and honored as a bridge engineer abroad as well as in his own country. His papers show that, in connection with the design and fabrication of the steel for the Forth Bridge, he was consulted by the late Sir Benjamin Baker, Hon. M. Am. Soc. C. E., with whom he contracted a warm friendship. In 1888 he visited England, and, at the request of Sir Benjamin Baker, read a paper before the British Association for the Advancement of Science, at Bath. This paper, entitled "Mechanical Pathology in its Relation to Bridge Design," attracted much attention, and was published in full, with illustrations, in *Engineering,* under the title "American Bridge Failures." It contains a great deal of valuable information in connection with the design of bridges, as derived from Mr. Thomson's long experience, and sets forth his principles of design. The latter are certainly in remarkably close agreement with the most approved practice of to-day, and show the advanced professional position of the man.

The engineering journals received many articles from Mr. Thomson's pen, and published many descriptions of his designs. Most of these are in the issues of the years 1888 to 1894, inclusive. His most recent contribution was a paper published in *Engineering News*, January 23d, 1908, entitled "Riveted Lattice for Railroad Bridges of Maximum Span: A Plea for a Return to Rational Design." He contributed freely to discussions of papers to this Society between 1887 and 1899, generally in connection with the design and construction of bridges.

Mr. Thomson was a man having a brilliant intellect, of the analytical type. He had a pleasing personality, and was a captivating conversationalist. His honesty was unquestioned. Frank and outspoken in his opinions, likes, and dislikes, he may have antagonized some, but he made many warm friends, and they were of the kind that stood by him through fortune and adversity. His wife, six daughters, and a son, the latter a Junior of this Society, survive him.

Mr. Thomson was elected a Member of the American Society of Civil Engineers on February 2d, 1887. He was also a Member of the British Institution of Civil Engineers, to which he was elected on May 7th, 1889, being one of the earliest American engineers to be thus honored.

RICHARD FENWICK THORP, M. Am. Soc. C. E.*

DIED JULY 28TH, 1908.

Richard Fenwick Thorp, the second son of the Reverend William Tudor Thorp, of Charlton Hall, Northumberland, England, was born on September 2d, 1868. His education was begun at Malvern College and continued at Richmond, Yorkshire. In 1887 he entered the Royal Indian Engineering College, at Cooper's Hill.

In 1890 Mr. Thorp entered the service of the Great Western Railway, first as unpaid assistant, later as full assistant, and then as Executive Engineer. During his seven years with this company, he made bridgework his special study. At the time he joined, the main line was being double-tracked, and, after assisting in the widening of Maidenhead Bridge (having two brick arches, each of 127 ft. span), Moulsford and Gatehampton Bridges (each having four brick arches, of 70 and 80 ft., respectively), he was put in charge of a 6-mile section which included the Kennet Bridge (a 60-ft. brick arch) and several large steel overbridges. In March, 1892, he was appointed on the staff of Mr. L. Trench, Chief Engineer, to inspect and report on the old iron and timber bridges on the whole of the company's system, and to design new superstructures where necessary. Some of these old bridges were the stone and timber viaducts erected across the Cornish valleys by Brunel, and, though in most cases they were perfectly sound, they were not suitable for the much greater traffic and heavier loads of modern times.

When this work was finished Mr. Thorp was put in charge of various new works for the company, and for two years was Executive Engineer in charge of the widening of the Berks and Hants Section, between Hungerford and Devizes (23 miles), which work included the designing of all necessary bridges.

In 1897 Mr. Thorp became Chief Engineer of the Kanan Devan Hills Products Company, in South India, and took up his duties there in March, 1898. The company had obtained from the Travancore Government, a concession of 200 sq. miles of land in the hills of North Travancore, known as the High Range, for the purpose of growing tea, coffee, cinchona, and other produce. The country, however, was almost inaccessible, communication being restricted to a few bridle paths. All materials and provisions were carried up from the low country on the heads of coolies or on pack bullocks and donkeys, wheeled vehicles being unknown in the hills.

The first works undertaken were a wire ropeway from the foot of the hills to the top, and, from the top of this ropeway to Munaar, the

* Memoir prepared by the Secretary from information furnished by Mr. Thorp's family.

center of the planting district, 20 miles of cart road on which was laid a Ewing one-rail tramway. The ropeway had a rise of 4 200 ft., was 2½ miles long, and was operated by electricity, generated by water-power at the bottom.

Then 10 miles of cart road were made (for the Madras Government) from the foot of the ropeway, to connect with the Government roads on the plains; and 38 miles of cart road were built from Munaar, to connect with the Government roads on the other, or northern, side of the concession (for the Travancore Government).

All these works were carried out with native labor, under Mr. Thorp's personal supervision, with one or two European assistants. All the necessary bridges were designed by him. The work of road making in these hills was by no means easy, on account of the rough and steep nature of the ground, the difficulty and expense of carrying up large pieces of ironwork, and, not least, the terrible havoc wrought by the Southwest Monsoon on anything but firmly established work.

By the time the roads were finished and other smaller works (such as water-power schemes for the various new factories of the district) were completed, the tea was grown up and coming into full bearing, and, although Mr. Thorp's original 5-year appointment was ended, the company asked him to remain and complete an electrical power scheme to facilitate the increasing work in as many factories as possible.

Near Munaar there is a large waterfall known as the Pullivasal Falls, giving a head of 380 ft. and a minimum supply of 2 000 ft. per min. A watercourse and head tank were built along the face of the rock at the head of the falls, and from there two pipes were conducted to the power-house in the jungle below, there operating two turbines coupled to two 100-kw. alternating-current generators. The current is transmitted, at 2 200 volts, over the hills in different directions to five factories at distances varying from 2 to 4 miles. There was great difficulty in erecting machinery in such steep and deeply wooded country. For some of the pieces, the bridle roads had to be widened, and their weight, considered only from the standard of human labor, was tremendous. It was completed, however, and worked successfully from the first day the power was applied.

In August, 1906, Mr. Thorp returned to England, and later entered into partnership with Mr. B. H. Thwaite. Soon after this, however, his fatal illness began, and, though he fought it with untiring patience and courage, he died in London on July 28th, 1908. He was buried at Alnwick, Northumberland, among his own people.

Mr. Thorp held strong views on the necessity for professional education and continual study, as well as practical experience, in the qualification of a Civil Engineer. He was one who, at all times, up-

held the honor of his profession, and was held in high esteem, by his colleagues, for his thorough professional knowledge; by his subordinates, for his just dealing; and by all, for his unimpeachable integrity.

He was made a Member of the Institution of Civil Engineers on March 28th, 1905, having passed through the preliminary grades of Student and Associate Member, and in 1907 was awarded the Crampton Prize for his paper on the "Munaar Valley Electrical Power Scheme."

Mr. Thorp was elected an Associate Member of the American Society of Civil Engineers on October 5th, 1904, and a Member on March 5th, 1907.

JAMES EAGER WILLARD, M. Am. Soc. C. E.*

Died March 8th, 1909.

James Eager Willard was born at Lowville, N. Y., on June 3d, 1832. He was educated in the local schools and at Lowville Academy.

He began his career as an engineer at the early age of seventeen, on the Black River and Erie Canals, on which he was engaged from 1849 to 1852, successively as Rodman, Draftsman, and Assistant Engineer. During this time, and while yet a very young man, he had responsible charge of important construction work, such as locks, aqueducts, culverts, bridges, and three reservoirs for feeding the Eastern Division of the Erie Canal. During the following two years, 1853 and 1854, he was engaged on the location and construction of the Utica and Black River Railroad, first as Transitman on location, and later as Division Engineer on the construction of 30 miles of the road.

In 1855 Mr. Willard re-entered the service of New York State and was engaged on canal work, serving for two years as Principal Assistant Engineer on the construction of the Black River Reservoir. In 1858 he was appointed a Resident Engineer on the Minneapolis and Cedar Valley Railroad.

From 1859 to 1871 Mr. Willard was engaged first in the banking and real estate business, and then in his father's extensive woolen mills, and other branches of manufacturing. His tastes, however, inclined him to return to engineering, and, in 1872, he accepted the position of Principal Assistant Engineer in charge of surveys for the Lake Erie, Evansville, and Southwestern Railroad.

Returning to the New York State Canal work, he was, in 1873 and 1874, Assistant Engineer in charge of the construction of locks at West Troy and Cohoes. After this he was interested, for about a year, in railroad contract work on the Cincinnati Southern Railroad, in Kentucky.

In the spring of 1875 Mr. Willard became Resident Engineer on the Cincinnati Southern Railroad, in charge of the construction of the foundations and masonry for the bridges over the Tennessee and South Chickamauga Rivers, and of other construction work, near Chattanooga, Tenn. This work was completed in 1876.

From 1877 to 1883 he was engaged, as U. S. Assistant Engineer, in charge of river improvement work, first at Colbert and Muscle Shoals, Tennessee River, under the direction of Major W. R. King, U. S. Engineer Corps, the work being on a large scale and done under the direct or hired labor system. Later, he was engaged on the improve-

* Memoir prepared by Samuel Whinery, M. Am. Soc. C. E.

ment of the Mississippi River, at Carolina Bend, La., under the direction of Major W. L. Marshall, lately retired as Brigadier-General and Chief of Engineers, U. S. A.

Resigning from the Government service in 1883, Mr. Willard, as Manager for the contractors, constructed the substructure for the bridge over the Ohio River at Henderson, Ky., involving pneumatic foundations. After the completion of that work he was employed, for a few months (1885), in installing a plant for tunnel work on the New Croton Aqueduct. During the same year he became a member of the firm of Sooysmith and Company, having direct charge of the field work of the firm for about six years. During this period a number of important bridges were constructed under his direction, among which may be mentioned that across the Mississippi River, at Keithsburg, for the Iowa Central Railroad; the foundations for the Burlington and Northern Bridge at Prairie Du Chien; the foundations for the Chicago, Milwaukee and St. Paul Railroad Bridge over the Missouri River at Kansas City; the bridge over the Mississippi River at Fort Madison, for the Atchison, Topeka and Santa Fe Railroad; the bridge at Sibley over the Missouri River; three bridges over the Ohio, two at Cincinnati and one at Louisville; and a bridge over Salt River at West Point, Ky.

After severing his connection with Sooysmith and Company, Mr. Willard went to Portland, Ore., and built the substructure of the bridge over the Willamette River, which involved difficult work, including the cutting off of the piles for the pivot pier 70 ft. below water surface. Shortly after this the firm of Willard and Cornwall, Contractors, was organized, and under Mr. Willard's direction, built the substructures for three bridges for the Atchison, Topeka and Santa Fe Railroad over the South Canadian and Cimmaron Rivers; one at Little Rock, Ark., with pneumatic foundations; one over the Illinois River at Pekin, Ill.; one over the Scioto River at Chillicothe, Ohio; and the Grays Ferry Bridge, at Philadelphia, the latter being completed in 1898. Most of these structures involved pneumatic work, and Mr. Willard, by reason of his natural abilities and experience, became recognized as an expert in that department of engineering work.

In 1900 and 1901 his firm constructed, by contract, Lock No. 4 on the Black Warrior River, in Alabama, and after this work was completed, the firm seems to have been dissolved.

In 1903 Mr. Willard was engaged, as Resident Engineer, on the construction of a timber-treating plant at Granada, Miss., for which Walter W. Curtis, M. Am. Soc. C. E., was Chief Engineer. The work, which cost about $225 000, was done by the day-labor method, under Mr. Willard's immediate direction.

From 1904 to 1906, he was engaged, as U. S. Assistant Engineer,

on the construction of Lock and Dam No. 6 on Green River, Kentucky, under the direction of Captain (now Major) H. Burgess, M. Am. Soc. C. E. Soon after this Mr. Willard engaged, with his son, in the lumber business in St. Louis, Mo., where he died on March 8th, 1909.

While Mr. Willard had not the advantage of an engineering education, he was able to attain, by study, hard work, and close application, a very creditable position in his profession. He possessed unusual executive ability, which fact, no doubt, led him into the field of contracting, where he was very successful in handling difficult work. One of his associates in some of these business enterprises, a Member of this Society, writes: "Mr. Willard was an able business manager in construction work." Another Member of the Society says: "I considered him as representative of the best type of American contractors"; and a Past-President of the Society writes: "I grew to entertain a very high regard for Mr. Willard as an engineer possessing great skill, sound judgment, and integrity. * * * We found that we could entirely rely upon Mr. Willard to do the work thoroughly well, promptly, and to the best advantage." The writer can personally testify that, as an assistant on a large and rather difficult work requiring ability, care, accuracy, and close application, he was efficient, trustworthy, and absolutely loyal.

Of Mr. Willard's personal character those who knew him most intimately will be warmest in their praise. Modest, retiring, and gentle speaking, it required close acquaintance with him to appreciate the rugged and forceful traits of character which lay beneath the surface, ready for action when occasion required. He was a good man, a good husband and father, a good friend, and a good engineer.

On June 29th, 1859, Mr. Willard was married to Margaret A. Brayton, whose death occurred several years previous to that of Mr. Willard.

Mr. Willard was elected a Member of the American Society of Civil Engineers on May 1st, 1899.

ROGER BROOKE IRWIN, Assoc. M. Am. Soc. C. E.*

DIED MAY 23D, 1910.

Roger Brooke Irwin was born at Westminster, Md., on March 13th, 1884. He was the son of the late Patrick H. Irwin, at one time Chief Engineer of the Baltimore and Ohio Railroad. Mr. Irwin received his early education in the public schools of Westminster, and was graduated at Mount St. Joseph's College with the degree of B. S., in 1901.

Upon graduation, he began his engineering career on the construction of the Roxborough Filtration Plant, at Philadelphia, Pa. Later he entered the employ of the Baltimore and Ohio Railroad Company on survey and construction work. He remained with this company, in various capacities, until October, 1903, when he became an Assistant Engineer for the Western Maryland Railroad and was placed in charge of the construction of coal and freight piers at Port Covington, Md., and hay sheds and coal yards at Hillen Station, Baltimore, Md. Later he was in full charge of the reconstruction of bridges. He severed his connection with this company in March, 1907. From March, 1907, to March, 1908, he was the senior member of the firm of Irwin and Case, General Contractors for a large amount of plain and reinforced concrete construction for the Baltimore and Ohio Railroad. During this time, Mr. Irwin was also City Engineer of Westminster.

From October, 1908, to May, 1910, he was employed as Chief of Party for the State Roads Commission of Maryland, in charge of survey work. He resigned this position to accept that of Road Engineer of Cecil County, which he held at the time of his death, on May 23d, 1910, at Elkton, Md.

Mr. Irwin was unmarried, and is survived by two brothers and two sisters. He was an able, energetic, and efficient engineer, and a man of strong character, with the highest ideals of courtesy, honor, and integrity. His disposition was such that he made friends wherever he went. He had the confidence and esteem of all who came in contact with him. He was thoroughly proficient in his work, and, had not death so suddenly cut short his career, his continued success and an honored position in his profession were assured.

Mr. Irwin was elected an Associate Member of the American Society of Civil Engineers on May 3d, 1910.

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* Memoir prepared by W. W. Crosby, M. Am. Soc. C. E.

VARDRY ECHOLS McBEE, Jr., Assoc. M. Am. Soc. C. E.*

Died June 20th, 1910.

Vardry Echols McBee, Jr., was born in Charlotte, N. C., on November 24th, 1879. He was the only son of V. E. and Rosa (Brooks) McBee, of South Carolina.

Mr. McBee was graduated from the Virginia Military Institute in 1899, and immediately accepted service with the Seaboard Air Line Railway. He became prominent in the location and construction of this railroad throughout the South, especially on its extensions into Columbia, S. C., Birmingham, Ala., and in Florida.

While in charge of a locating party on the West Coast of Florida, Mr. McBee succumbed to an attack of paralysis, and after an illness of two weeks, he died in the hospital at Ocala, Fla., on June 20th, 1910.

In 1907, Mr. McBee was married to Miss Marie Hudgins, of Alabama, who, with an infant daughter, his father, mother, and sister, is left to mourn his loss.

Although taken away at the early age of 30 years, Mr. McBee was recognized as a man of exceptional ability and high professional talent. By his death the Profession has lost a most promising railroad engineer, the country a good citizen, and his friends a friend indeed; but a loving soul has returned to the God that gave it.

Mr. McBee was elected an Associate Member of the American Society of Civil Engineers on October 7th, 1908.

* Memoir prepared by L. P. Slattery, Assoc. M. Am. Soc. C. E.

RALPH CARROLL SOPER, Assoc. M. Am. Soc. C. E.*

DIED JUNE 16TH, 1910.

Ralph Carroll Soper was born on February 3d, 1881, at South Royalton, Vt., at which place his early education was obtained. He was graduated from Dartmouth College with the degree of A. B. in 1902, and from the Thayer School of Engineering with the degree of C. E. in 1904.

Mr. Soper began his professional career with the Illinois Steel Company, where he was employed until May, 1905.

On May 1st, 1905, Mr. Soper was appointed as Engineering Aid in the United States Reclamation Service, and assigned to work on the preliminary surveys of the Shoshone Project, Wyoming. On May 1st, 1907, he was advanced to the grade of Assistant Engineer, and assigned to work on the Corbett Tunnel, Shoshone Project, which position he filled until the completion of the tunnel in 1907. He afterward held various responsible assignments on the Flathead and Shoshone Projects and in the office of the Supervising Engineer.

On the evening of June 16th, 1910, while on a pleasure trip in a motor-boat on the Shoshone Reservoir, near Cody, Wyo., with four other employees of the Reclamation Service, the boat unfortunately upset, and Mr. Soper and three of his companions were drowned.

Mr. Soper was possessed of many sterling qualities, and commanded the respect of his associates and those under and over him in authority. His work at all times showed great possibilities for his ultimate success, and his loss will be much regretted by the Service, from a professional standpoint, and particularly by the numerous friends and acquaintances which his pleasing personality and good nature had made for him in his work.

Mr. Soper was elected an Associate Member of the American Society of Civil Engineers on August 31st, 1909.

* Memoir prepared by H. N. Savage, M. Am. Soc. C. E.

NORMAN ALFRED TAYLOR, Assoc. M. Am. Soc. C. E.*

DIED AUGUST 29TH, 1910.

Norman Alfred Taylor was born at Troy, N. Y., on January 12th, 1880. He received his early education at St. Paul's School, Troy, N. Y., and at the Troy Academy. At the Rensselaer Polytechnic Institute, from which he was graduated in 1902, Mr. Taylor was a prominent member of the Theta Xi Fraternity.

After he was graduated Mr. Taylor was connected with the firm of Snow and Barber of Boston, Mass., and assisted in the preparation of the plans and the installation of the sewage disposal system for the Village of Saratoga, N. Y. On the completion of this work he was appointed Assistant City Engineer of Troy, N. Y.

For five years Mr. Taylor was connected with the Highway Department of the State of New York, having charge of the construction of an extensive system of roads in Eastern New York.

In the spring of 1910 he was engaged by the Standard Oil Company, in the capacity of Engineer, in the construction of bituminous highways, with headquarters at Baltimore, Md. While in that city he contracted typhoid fever, from which he died in Poughkeepsie, N. Y., on August 29th, 1910.

Although quiet and unassuming in his manner, Mr. Taylor was loved by all who knew him, for his personal qualities and for his ability as an Engineer. He had a rare capacity for detail, nothing in connection with his work being too unimportant to claim his careful personal attention.

Mr. Taylor married Miss Alice Reynolds of Troy, N. Y., who, with three children, Elizabeth, Catherine and Robert M. 2d, survives him. He is also survived by his father, Mr. Robert M. Taylor, and a sister, Miss Ruth Taylor, of Troy, N. Y.

Mr. Taylor was elected a Junior of the American Society of Civil Engineers on October 6th, 1903, and an Associate Member on December 5th, 1906. He was also a Member of the Society of Engineers of Eastern New York.

* Memoir prepared by John Flynn, Jr., M. Am. Soc. C. E.

SILAS GILDERSLEEVE COMFORT, Assoc. Am. Soc. C. E.*

DIED JULY 13TH, 1910.

Silas Gildersleeve Comfort was born at Triangle, Broome County, N. Y., on April 27th, 1863. He was the son of the Reverend Silas Comfort, D. D., a prominent Methodist clergyman, and Sarah Ann Foster Comfort.

On his father's side, Colonel Comfort was descended from Robert Comfort who, with two brothers, came to this country from England. His great-great-grandfather, Robert Comfort, the son of the first Robert Comfort, married Elizabeth Betts, daughter of Captain Richard Betts and Mercy Whitehead Betts (the Hicksite Quakeress), of Newton, L. I., whose family was promient in the settlement of Long Island. His great-grandfather, Richard Comfort, served in both the Nester and Dutchess County Militias during the Revolutionary War, and his grandfather, John Comfort, who was a promient merchant, built the Delaware-Susquehanna Division of the National Road, between the Hudson River and Lake Erie, which was afterward made the route of the Erie Railroad.

His parents died when he was about six years old, and he was reared by his half-brother, George Fisk Comfort, an eminent scholar, art critic, and author, and his wife, Anna A. Manning Comfort, a prominent physician and writer. Dr. Comfort gave him all the available advantages of education, treating him as a son. He was tutored by his half-brothers, and studied at private and public schools and at Syracuse University, from which he was graduated, receiving, in 1882, the degree of B. C. E. from the College of Liberal Arts, and, in 1884, the degree of B. Ar. from the College of Fine Arts. In 1887, he received the first Master's degree in architecture (M. Ar.) ever given by an institution in America.

During his college vacations Colonel Comfort had charge, for a time, of the construction work on the then new West Shore Railroad, between Utica and Savannah, N. Y., and was also employed by the Phœnix Iron Company, at Phœnixville, Pa., obtaining, in this way, much practical instruction before he was graduated. He had a special liking for the engineering of structural steel, of which he was a close student, and this fact, coupled with his unquestioned mathematical ability, rapidly advanced him in the estimation of the best engineers of that period.

In the summer of 1884 Colonel Comfort became Instructor in Mathematics and Technical Drawing at the Pennsylvania Military College (then the Pennsylvania Military Academy), at Chester, Pa. In 1887 he was appointed Professor of Architecture and Instructor in

* Memoir prepared by St. George H. Cooke, Assoc. M. Am. Soc. C. E.

Civil Engineering and Technical Drawing, and in 1889, received the degree of C. E. from that institution. In 1892 he was made Professor of Engineering and Astronomy, and was appointed Captain and Adjutant of the College. In 1895, he was advanced to the position of Vice-President and was commissioned a Lieutenant-Colonel by the State of Pennsylvania.

At the time of his death, Colonel Comfort had been a faithful and efficient officer of the Pennsylvania Military College for twenty-six years, and graduates from the institution during that time remember with profit his plainly spoken words of advice.

During his residence in Chester, he designed much structural steel work, notably that for the Library of Yale University. The day before his death, he was appointed Consulting Engineer of the City of Chester, to supervise municipal work, the cost of which was estimated at more than $1 500 000.

Colonel Comfort was a Past-President of the Engineers' Club of Philadelphia; a Mason; and a Member of the American Geographical Society. He was also a Member of the Penn Club of Chester, President of the Board of Trustees of the Third Presbyterian Church, and a Member of the School Board, in which capacity he had served the city for a number of years, and was looked to for advice in regard to the school system of the municipality.

He was a Charter Member of the Sigma Psi Society which, later, became the Syracuse Chapter of the Phi Delta Theta Fraternity.

He is survived by his widow and two children, by a sister, Miss Grace M. Comfort, of New York City, and a half-brother, Melville Lane Comfort, of Monroe, Mich.

Colonel Comfort was elected an Associate of the American Society of Civil Engineers, on March 31st, 1891.

GEORGE HIGGINS MYERS, Jun. Am. Soc. C. E.*

DIED OCTOBER 10TH, 1910.

George Higgins Myers was born at South Bend, Ind., on April 12th, 1883. He was graduated from the South Bend High School in 1901. In September, 1902, he entered Purdue University as a student in the Mechanical Engineering Department, but was compelled to give up his college course in January, 1905, on account of failing health.

From April to June, 1905, he served as Field Draftsman on the relocation survey of the Gila Valley, Globe and Northern Railway, and from July to December, 1905, he was employed as Draftsman and Calculator for F. C. Kelsey, Civil Engineer, of Salt Lake City, Utah.

From January to May, 1906, Mr. Myers studied surveying and masonry construction under G. E. P. Smith, Assoc. M. Am. Soc. C. E., University of Arizona. In July, 1906, he came East and entered the employ of the Ransome and Smith Company, of New York City, acting as Engineer and Foreman on the construction of the Ansonia, Conn., Brass Foundry, until December of the same year.

In March, 1907, he was appointed Designing Engineer of the Trussed Steel Concrete Company, which position he held until July, when he became Concrete Engineer and Superintendent for H. G. Christman and Company, Contractors, of South Bend, Ind.

In May, 1908, Mr. Myers returned to the West, serving as Denver Agent for the Trussed Steel Concrete Company until October. During this time he designed the roof and floors of the Cheesman Memorial.

In October, 1908, he entered the employ of Charles G. Sheely, Bridge Contractor, of Denver, Colo., as Assistant Engineer in charge of reinforced concrete and structural steel work. He remained with Mr. Sheely until 1910, when he took up his residence in Tucson, Ariz., where, on October 10th, he died from the effects of a pulmonary hemorrhage.

Mr. Myers was especially interested in concrete construction, and was a young man of great promise in his chosen profession.

Mr. Myers was elected a Junior of the American Society of Civil Engineers on June 1st, 1909.

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* Memoir prepared by the Secretary from information supplied by C. H. Myers, M. D., and from material on file at the House of the Society.

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OF THE

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